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Project Title

**Investigating the Potential of the Magnetic Separation Method as an Auxiliary
Technique for Upgrading Lithium Ore Mineral from Kenticha Pegmatite
Deposit in Guji, Southern Ethiopia**

By

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List of Acronyms

AAS	Atomic Absorption Spectroscopy
CC	Concentration Criteria
CDMS	Conventional dry magnetic separator
DMS	Dense Media Separation
DREMS	Dry Roll Electromagnetic Separator
EMPBC	Ethiopian Mineral, Petroleum, and Biofuel Corporation
CEGLI	Central Ethiopia Geological Laboratory Institute
LCT	Lithium Cesium Tantalum
HIMS	High Intensity Magnetic Separator
REE	Rare Earth Elements
ROM	Run Of Mine
MSIMS	Magnetic Separators With Improved Magnetic Systems
MSOFF	Magnetic Separators With Enhanced Force Fields
WHIMS	Wet High Intensity Magnetic Separator
XRD	X-ray Powder Diffraction

Abstract

Lithium has become a critical mineral in the energy industry, with significant increases in usage due to the global shift towards green energy alternatives over the past decade. The Kenticha pegmatite deposit in Ethiopia is known to have a feasible content of Li_2O , making it a potentially valuable resource for lithium extraction. However, the beneficiation of lithium-bearing minerals is a crucial stage in upgrading the lithium oxide content of the ore and enhancing its economic value. The presence of gangue minerals such as microcline, albite, quartz, muscovite, and iron silicate minerals can complicate the process. Frantz magnetic separators were employed to conduct magnetic separation tests. Samples were collected from four different locations within an upper lithium-rich pegmatite deposit and subjected to analysis, revealing varying percentages of lithium oxide and iron oxide. The effectiveness of a Frantz magnetic separator was examined using feed size fraction and intensity as independent variables, with various combinations of factors tested. The resulting data was analyzed using AAS and XRD techniques to gain valuable information about the separation process and lithium mineral liberation. The separation effectiveness was evaluated based on the results, which indicated that high-intensity magnetic experiments with fine feed size fractions achieved better recovery of lithium oxide and less iron-bearing minerals. The potential for using the magnetic separator as part of a larger processing plant was also discussed, with comparisons magnetic separation method to other conventional lithium processing methods that employed magnetic separation. Finally, potential types of magnetic separators were suggested for the LCT Kenticha pegmatite deposit.

Keywords; kenticha pegmatite, spodumene, Lithium, beneficiation, upgrading, magnetic separation, gangue minerals, magnetic susceptibility, Magnetic separator

1. INTRODUCTION

1.1. STUDY BACKGROUND

Lithium, with its atomic number of 3 and atomic weight of 6.94, is the lightest of all metals and possesses unique chemical and physical properties. Lithium carbonate, lithium hydroxide, and lithium bromide are used not solely in conventional applications like glass and ceramics but also in cutting-edge technologies like electric vehicles, solar panels, and electronic devices as they are becoming more widely acknowledged as strategic minerals (Camille, 2012). Given the growing demand for renewable energy sources, it is predicted that the demand for lithium will skyrocket in the coming decades, making it crucial to ensure a sustainable and sufficient supply for the global market.

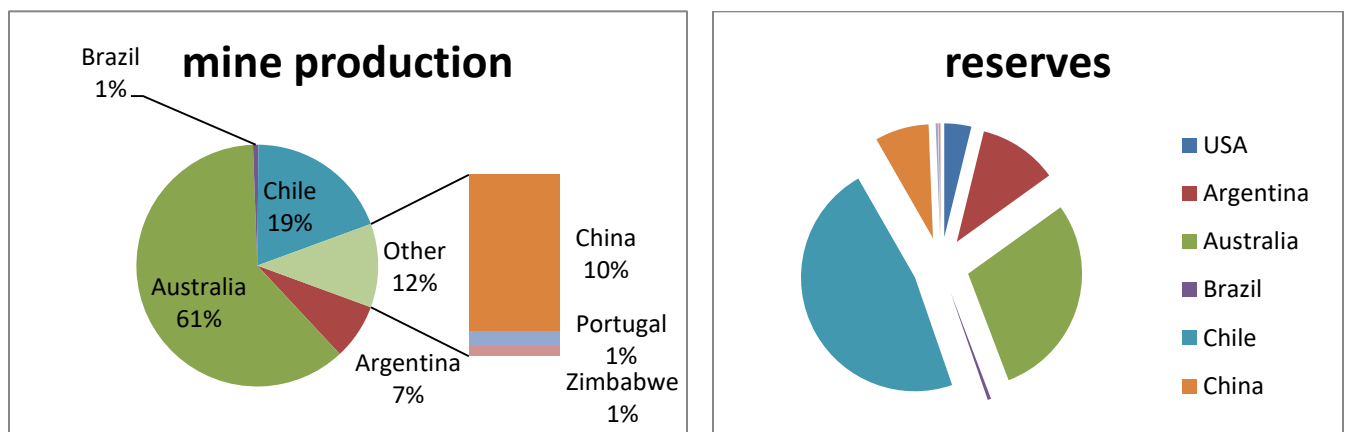


Figure 1. world lithium reserve and mine production in percentage (“Mineral Commodity Summaries 2022 - Lithium)

Lithium could be obtained economically from intrusive pegmatite rock and brines. Over 60% of the total lithium produced worldwide is comes from brines, with the remaining 40% coming from lithium ores (Arlene Ebenspergera, PhilipMaxwell. b,ChristianMoscosoc, 2005). Lithium ores are typically hosted in intrusive granitic igneous rock called pegmatite, which are complex hard rock deposits of aluminum silicate. Pegmatite deposits are the primary mineral sources of lithium due to their relatively coarse grains, which make processing easier (Tadesse B. , 2019). Pegmatite are intrusive granitic rocks made primarily of quartz, feldspar, spodumene, and mica mineral grains that interlock with one another (Colton, 1957).

Lithium hosting pegmatite deposit contain lithium bearing minerals such as spodumene, petalite, lepidolite, amblygonite zinnwaldite, triphylite and eucryptite (Tadesse B. , 2019). The most often used commercially extracted lithium mineral is spodumene, which contains up to about 8% Li_2O (levich, 2009). Spodumene is an alumino-silicate crystal that has a formula of $\text{Li}_4\text{Al}_4[\text{SiO}_3]_8$, is composed of silica tetrahedra that are joined laterally by ionic bonding with lithium and aluminum in octahedral coordination, and is found in pegmatite deposits together with micas, albite, and quartz. (Colton, 1957).

In both brine and hard rock, Ethiopia has significant lithium reserves. Afar is considered to be the key area of interest for the possible location of lithium-related evaporates or brine deposits (AssnakeBekele, 2020). In the hard rock lithium minerals (lepidolite, spodumene) are found in pegmatite hosted Colombo-tantalite mineral deposits in Kenticha pegmatite field (Tadesse S. , 2000)

The EMPBC were mining Kenticha pegmatite deposits to extract tantalum from niobite and tantalite ore minerals. Recently, a lithium mining company expressed interest in the Kenticha pegmatite deposit. The Kenticha pegmatite deposit has a lithium resource that is estimated to be 67.4 million metric tons at 0.73 percent of lithium oxide and The deposit higher-grade fresh rock component has 47.3 metric tone at 0.85 percent of lithium oxide (“Abyssinian Metals | a World Class Battery Metals Project,” n.d.).

The Kenticha LCT pegmatite deposit in Ethiopia is known to contain significant amounts of lithium ore, specifically the mineral spodumene. However, the beneficiation of spodumene from this deposit has not been extensively studied. Beneficiation is a crucial step in increasing the amount of Li_2O in the ore. Utilizing crushing and grinding equipment, the lithium ore is separated from the gangue minerals in this process. According to Aghamirian, Mohs, Grammatikopoulos, and Imeson, 2012 washing, hand sorting, and classification of ROM are steps some lithium ore processing plants take to reduce micaceous and clay minerals and ultimately improve mineral liberation and increase lithium ore recovery. The primary methods for beneficiating lithium minerals rely on the deposit's mineralogy. Lithium ore beneficiation flow sheets include gravity (DMS), magnetic separation, and froth flotation (Tadesse B., 2019). The lithium pegmatite deposit that contains iron-bearing impurities like amphibolite and tourmaline was separated using magnets separation process (Tadesse B., 2019).

According to magnetic susceptibility, paramagnetic minerals are separated using the Frantz Isodynamic, a bench-scale magnetic separator (Murty, 1963). The procedure involves feeding the mineral sample into a magnetic field via an inclined chute that travels along the electromagnetic circuit. The magnetic susceptibility of the mineral grains determines how they react to the magnetic field when they move through areas with high magnetic gradients. Mineral liberation is also evaluated using the Frantz isodynamic. The Frantz Isodynamic Method is used to independently treat the various size fractions of the mineral sample. The degree of liberation can be determined by examining the chemical analyses of the magnetic and nonmagnetic stream across the size spectrum (A. Wills, James A. Finch, 2016).

1.2. STATEMENT OF PROBLEM

As the world moving to renewable energy sources, it is predicted that demand for lithium will soon surpass oil and gas. Lithium is one of the most important raw materials in lithium ion batteries and other industrial use. Beneficiation of the Li ores is critical to increasing the economic value of the resource by producing a globally marketable lithium concentrate. Therefore, it is necessary to develop a beneficiation circuit that is appropriate, affordable, and environmentally friendly and capable of enhancing the target mineral at a commercially feasible lithium oxide level.

Several studies such as ("Abyssinian Metals | A World Class Battery Metals Project,"), and D. Kuster et al., 2009, and Tadesse and Zerihun, 2009 demonstrated that the Kenticha LCT pegmatite deposit has good potential for lithium ore minerals at economic content of Li_2O . However, as far as known, There is no report available on Benefaction of LCT pegmatite for this specific deposit. In addition, none of the known reports investigated the effectiveness of magnetic separator for LCT Kenticha pegmatite deposit. To address this gap in knowledge, this study aims to analyze Potential of Magnetic Separation Method as an Auxiliary Technique for Upgrading Lithium-Bearing Mineral from Kenticha Pegmatite Deposit. Using various size fractions and magnetic intensities. The outcomes of this project provide valuable information on the liberation of lithium minerals across different size fractions, and also offer insights for future research. Furthermore, these findings can support in the development of an efficient beneficiation process for the Kenticha lithium-bearing pegmatite deposit.

1.3. OBJECTIVE

1.3.1. General Objective

The general objective of this project is to investigate the Potential of Magnetic Separation Method as an Auxiliary Technique for Upgrading Lithium Ore Mineral from Kenticha Rare Metal Pegmatite Deposit.

1.3.2. Specific Objective

The specific objectives of this project are;-

- Determine the effect of magnetic intensities in a dry magnetic separator to remove iron-bearing minerals.
- Analyze the effect of different size friction ranges of feed on performance of magnetic separator during the process.
- Perform recovery of lithium-bearing minerals in the nonmagnetic stream of the magnetic separator, characterize minerals in the magnetic stream, and assess lithium mineral liberation at different size fractions.
- Examine the efficiency of magnetic separator in removing iron bearing impurities and concentrating lithium bearing mineral.
- Compare the result obtained from the bench-scale electromagnetic separation test with that obtained from other conventional spodumene beneficiation techniques, such as flotation and DMS.

1.4. SIGNIFICANCES OF THE PROJECT

Lithium is becoming a strategic material in the new future as it has diverse applications in industrial, chemical, and metallurgical fields. Recently, new lithium-based energy storage devices are creating an extra demand for lithium, which is predicted to boom in the near future. Several literature sources reported that Ethiopia has high potential for lithium primarily associated with the Kenticha pegmatite deposit.

This deposit will play an important role in Ethiopia's economic transformation if it is developed and a proper beneficiation circuit is planted in place. The investigation of the Potential of Magnetic Separation is the main emphasis of this project. On the accomplishment of this project, the following implication is expected:

- ✓ This work serves as a valuable addition to the existing data on lithium ore minerals from the LCT pegmatite deposit and as a source of information for an upcoming study.
- ✓ This Work provide suggestions and information for the rational development and utilization of the deposit as well as it will provide a reasonable level of recovery prediction, which also can provide a reference for the development and utilization of the Kenticha pegmatite Deposit.
- ✓ Improves lithium concentrate quality.
- ✓ This project has the potential to benefit Ethiopia with significant reserves of lithium, developing a cost-effective and efficient method for extracting lithium from the ore can unlock its potential. By exporting high-quality lithium concentrate, Ethiopia can tap into the growing market for lithium and generate hard currency revenues that can be used to support the country's economic development.

1.5. SCOPE OF THE STUDY

The scope of this research is to explore the potential of the magnetic separation Method as an auxiliary technique for enhancing the quality of lithium Ore minerals extracted from the Kenticha Pegmatite Deposit. The study evaluated the impact of feed size fraction and magnetic field intensity on the percentage recovery of lithium minerals as well as the effectiveness of the separator in rejecting iron-bearing minerals. Additionally, this study compared the results obtained from the bench-scale Frantz Magnetic Separator with other conventional lithium ore mineral processing methods. The experimentation conducted in a laboratory setting using lithium ore from the Kenticha Pegmatite deposit. The findings of this research provides valuable insights into the advantages of incorporating magnetic separation as part of the lithium beneficiation circuit and will inform strategies to improve the recovery of lithium ore during beneficiation processes for the Kenticha LCT pegmatite deposit and other similar deposits.

2. LITERATURE REVIEW

2.1. Introduction

This chapter reviews the relevant literature published within the fields of this project to provide background on the main focus areas of the project. The geology and mineralization of the Kenticha deposit are described, along with the lithium-bearing mineralization. The section reviewed various beneficiation methods used for upgrading different lithium-bearing minerals from hard rock, with a specific focus on magnetic separation techniques. The fundamentals, working principles, and factors affecting the Frantz electromagnetic separator are also discussed to enhance understanding of the equipment.

2.2. Geology and Mineralization of Kenticha Pegmatite

The Kenticha pegmatite is situated within the Precambrian basement of southern Ethiopia. Kenticha pegmatite deposit encompasses an area of roughly 2,500 km² (Tadesse S. , 2000). The pegmatites were emplaced close to, but mainly west of, the NNE–SSW striking Kenticha thrust shear zone. Highly fractionated hydrous residual melt batches of volatile- and incompatible-enriched felsic magma masses give rise to pegmatite crystallization. When minerals are separated from the magma by crystallization during fractional crystallization, water and other elements that do not reach the minerals will become the final by product of the original magma. Incompatible substances, fluxes, volatiles, and rare elements are added to residual melts. The most significant volatile is water. Beryllium, lithium, boron, phosphorous, fluorine, niobium, tantalum, and cesium are some examples of the rare elements (Kuste, Tadesse and Zerihun, 2009). Zerihun,1995 used mineral parageneses and trace element geochemistry of muscovite and microcline to classify pegmatites of the Kenticha field into barren feldspar–muscovite pegmatites and different types of rare-element pegmatites.

Kenticha rare element pegmatite deposit shows asymmetric internal mineral zonation with from the base to the top a granitic to aplitic wall zone. The upper zone of the Kenticha deposit constitute the more than half of entire pegmatite deposit, which contains up to 3.0 wt% Li₂O and other REE in ppm, is the most economically significant component mineralization in Kenticha pegmatite ore (Kuste, Tadesse and Zerihun, 2009).

The spodumene unit is effectively continuous and is composed of a coarse grained muscovite–quartz–albite–microcline–spodumene pegmatite assemblage. Spodumene is greenish-white and characteristically occurs in giant wedge-shaped crystals up to 4 m in length. albite displays variable grain sizes, and microcline may be amazonitic in places. The albite unit is characterized by high proportion of fine grained saccharoidal albite and occurs in discontinuous spherical bodies throughout the spodumene-bearing pegmatite (küster, D, Romer, R.L, Tolessa, D., 2008).

2.3. Lithium Bearing Minerals

Lithium is extracted from hard rock deposits, which is a far more difficult and energy-consuming process. Lithium is abundantly dispersed in hard rock and is typically found in complex aluminum silicate Deposits known as pegmatite in the form of mineral spodumene (LiAlSi₂O₆), petalite (LiAlSi₄O), lepidolite [(KLi₂Al(Al,Si)₃O₁₀(F,OH)₂10], amblygonite [(Li,Na)AlPO (F,OH)], and eucryptite (LiAlSiO₄)₄) (Tadesse B. , 2019), (Colton, 1957) (Bulatovic, S.M, 2015). The primary sources of lithium production are spodumene and, to a lesser extent, petalite and lepidolite (Bulatovic, S.M, 2015).

2.3.1. Spodumene

Spodumene is a monoclinic pyroxene with a single-chain structure and contains about 8% of Li₂O, 64.5% SiO₂, and 27.5% Al₂O₃ (Bulatovic, S.M, 2015). Spodumene is found mainly in association with quartz, mica amblygonite, beryllium, and tantalum in granite-pegmatites as crystals of various sizes. The color of spodumene is shiny, yellowish, or blue (Bulatovic, S.M, 2015). Due to its significant lithium content and the presence of substantial deposits, spodumene is the primary lithium containing silicate material that is currently being explored and exploited (Garret, 2004). Heavy media separation, froth flotation, and magnetic separation are widely used methods to concentrate spodumene (Tadesse B. , 2019).

2.3.2. Other Lithium Minerals

Apart from spodumene, lithium minerals such as petalite, lepidolite, amblygonite and eucryptite are potential lithium bearing minerals in the pegmatite hard rock (Tadesse B. , 2019). Lepidolite is mica that is utilized in the manufacture of glasses and ceramics. Its composition is complex and variable. Lepidolite is often a brittle mineral with Al_2O_3 concentrations ranging from 11.3% to 28.8%, SiO_2 ranges from 46.9 to 60.1, Li_2O ranges from 1.5% to 5.5%, and fluorite at 9% (Bulatovic, S.M, 2015). Rubidium can be found in lepidolite up to 3.7% Rb_2O and cesium at 1.5% Cs_2O . Calcite, muscovite, feldspar, and quartz are the principal gangue minerals that are occurring in association with lepidolite and need to be rejected in order to upgrade lepidolite. Petalite has silicate structure which usually associated with other li bearing minerals such as spodumene, eucryptite.

2.4. Beneficiation Methods Of Spodumene Ore

The process of upgrading the amount of Li_2O in spodumene ore through physical separation is known as beneficiation. Beneficiation of the ore is one of the first phases in extractive metallurgy, and it primarily serves to get the spodumene ore ready for future purification procedures. Comminution, size classification, and concentration are the methods employed in ore beneficiation the most frequently (A. Wills, James A. Finch, 2016). Due to the physical-chemical resemblance among lithium minerals and their associated gangue minerals, such as quartz, feldspar, etc., beneficiating lithium can frequently be a challenging task (Bulatovic, S.M., 2015). The kind of concentrate varies depending on the impurities in the spodumene crystal lattice and the distribution of particle sizes. Therefore, the beneficiation techniques needed to concentrate spodumene are heavily influenced by the mineralogy. (Oliazadeh, Aghamaria, Ali, & Legalult, 2018) Spodumene ore is improved to produce concentrate of potentially a chemical or ceramic grade.

to liberate the lithium minerals from Sample and change the size reduction for the ensuing beneficiation procedure, spodumene is upgraded using crushing and grinding procedures (Bulatovic, S.M., 2015). In a general flowsheet for the methods of beneficiating lithium ores, Tadesse B., 2019, incorporated froth flotation, magnetic separation, and gravity separation (DMS). The color variations between the lithium and gangue minerals are also used in hand sorting, a potential pre-concentration process. This method is typically used when the lithium minerals are present as large crystals. Petalite ores can benefit the most from this method (Bulatovic, S.M., 2015). By removing amphibole and pyroxene from the ore before it enters the beneficiation plant and by avoiding mine dilation, ore sorting improves lithium-bearing pegmatite processing. It is most effective to eliminate these minerals at the beginning of the process because they are frequently found in the gangue rock of lithium-bearing pegmatite ores, tend to interfere with DMS and spodumene flotation operations, and can be tough to remove from spodumene (oliazadeh, aghamaria, Ali, & legalult, 2018). The development of advanced optical ore sorting is ongoing. High-capacity optical sorters with a quick-scanning laser beam have been built for sorting heavy-duty ore (Schapper, 1977).

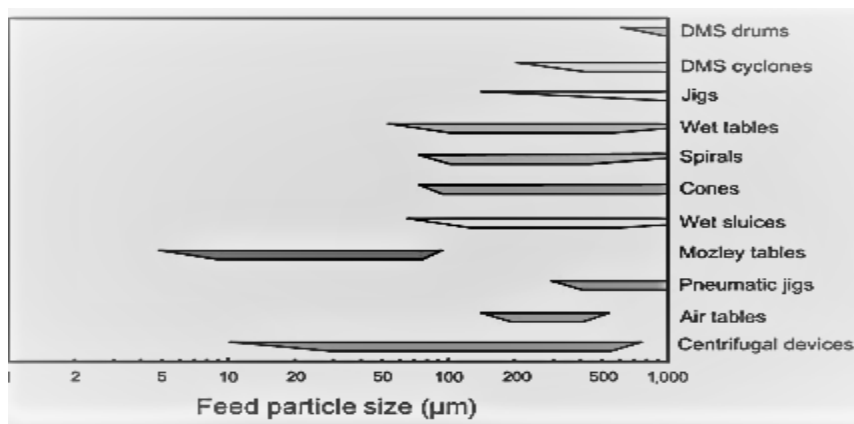


Figure 2.1. Appropriate feed size range for processes using gravity and dense medium (A.Wills,James A. Finch,, 2016)

Using a series of shaking tables, spirals, DMS drums, and jigs, gravity separation is carried out. Figure 2.1 depicts how to select a gravity separator by considering the range of feed material particle sizes. One of the earliest and most widely used industrial methods for coal and mineral beneficiation is gravity concentration (A. Wills, James A. Finch, 2016).

2.4.1. Magnetic Separation Method.

Magnetic method Separate minerals based on their magnetic susceptibility contrast between target mineral and gangue minerals. The magnetic susceptibility contrast between particles, which can be ferromagnetic, paramagnetic or diamagnetic (A.Wills,James A. Finch,, 2016). The separation from one materials from another or the removal of magnetic particles from feed is determined by the motion of magnetic particles in response to the magnetic force and other competing external forces, such as gravitational, inertial, hydrodynamic, and centrifugal forces. (Wills, B. A., & Napier-Munn, T, 2006).

In the mineral processing industry, dry, permanent magnetic separators are available in a variety of forms. There are three types that are commonly employed: Magnetic separators with enhanced magnetic systems (MSIMSs), modified fields of force (MSOFFs), and typical dry magnetic separators (TDMSs) (Shunping Xie, Zhicheng Hu, Dongfang Lu * and Yan Zhao, 2022). In order to remove the gangue, the conventional dry magnetic separator (CDMS) makes use of the drum's centrifugal force. It is mostly utilized to remove the surrounding rocks that were mixed up with the ore in order to recover the geological grade of the bulk magnetic materials (Shunping Xie, Zhicheng Hu, Dongfang Lu * and Yan Zhao, 2022).

The magnetic separation method that is employed for a particular ore is selected according to the magnetic characteristics of the target and associated gangue minerals in the ore. Magnetic

method used as an auxiliary method to improve the quality of spodumene concentrate. It is most common to perform after flotation to produce low iron content that concentrate that is suitable for ceramics and glass manufacture (Tadesse B. , 2019) .

2.5. Frantz electromagnetic separator

The isodynamic separator, known as the Frantz magnetic separator, was invented by Samuel G. Frantz in 1936 and became widely used around 1971. This device is calibrated with known magnetic susceptibilities of various substances, allowing for the deduction of magnetic susceptibilities of other substances (Murty, 1963). It plays a vital role in mineral concentration processes by separating minerals from a mixture of dry grains based on their paramagnetic nature. The device consists of a vibrating inclined chute positioned between two poles of an electromagnet that directs the sample into one of two collection Bins. The electromagnet applies an electromagnetic force in competition against the gravitational force, with the "non-magnetic" collection cup collecting material where gravity overcomes the magnet's attractive force and the "magnetic" collection cup collecting the remaining material.

2.4.4. Frantz magnetic separator working principles

The aluminum tray is designed with two channels and positioned at an angle to create a slope for smooth feed passage. A magnet is placed above the tray in parallel alignment. The tray is specifically constructed to receive dry material from the hopper without any disturbance. The sample moves downwards over the channel due to the influence of the magnet and vibration, which can be adjusted to regulate the feed rate and grain movement. Similarly, the magnetic field intensity can be controlled to separate minerals with desired susceptibility levels, such as using a minimum intensity of 0.01 A for highly magnetic minerals and a maximum of 1.70 A for those with lower susceptibility (Strong, T. R., & Driscoll, R. L. , 2016). To prevent recombination, the particles split mechanically while they are still in the field. With respect to gravity, the magnet, pole components, and tray can be positioned in any direction. The longitudinal tray angle and vibration amplitude both affect how quickly particles move through the field.

The separated minerals are directed to either the left or right channel based on their paramagnetic or non-magnetic nature, and collected in bin-type containers at the end of each tray chute (shown

on Figure. 3.6A).The longitudinal tray angle was kept constant at 20° for the bulk of testing. The transverse angle controls the magnitude of the gravity force in respect to the magnetic force. A paramagnetic particle is said to have a positive tray angle when the magnetic force exerted on it is oriented in the transverse direction.

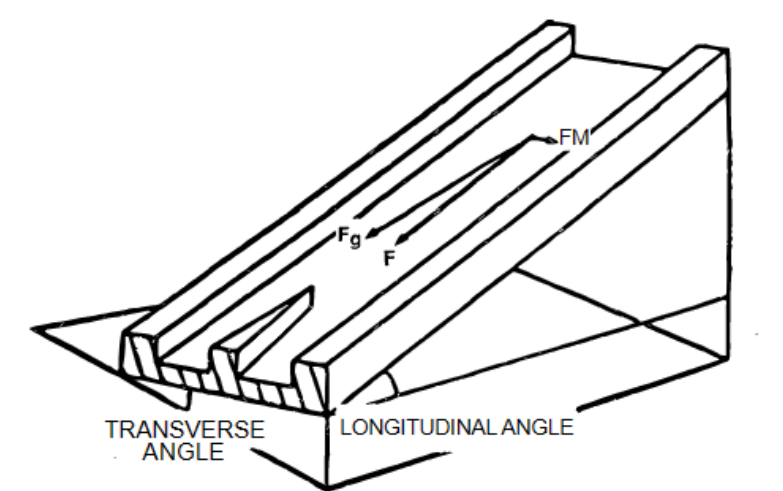


Figure 2.2. Forces impact on a particle down the separator's chute of the Frantz model LB-1. (Hoegler, J. M., and W. M. Bradshaw, 1989)

Where as

Gravity F_g , drag F^{\wedge} , and magnetic forces F_m act on a particle in a magnetic field. For a single sphere in a magnetic field, these forces are;

$$F_g = pVg$$

$$,F_q = 3npdv$$

$$F_m = XHV$$

grad (B), Where;

p = particle density,

V = particle volume,

g = acceleration due to gravity,

d = effective particle diameter,

y = fluid viscosity,

v = fluid velocity,

X = magnetic susceptibility,

H = magnetic field intensity, grad B = magnetic flux density.

In General, the review covers various aspects, including the geology and lithium ore minerals found in the deposit, different types of separation processes for lithium ore minerals from the pegmatite deposit, and a thorough examination of the fundamentals of magnetic separation. Additionally, the review explores different types of magnetic separators and factors that can impact separation efficiency. However, the beneficiation of lithium ore minerals for this specific deposit has not been studied thus far, and the potential of a magnetic separator as an auxiliary technique has not been thoroughly investigated.

3. MATERIALS AND METHODS

3.1. Time and Place of the Study

The study was carried out between March 2023 and June 2023 at Addis Ababa University, Addis Ababa Institute of Technology: School of Chemical and Bio Engineering in Process Engineering laboratory (AAiT), and Geological Institute of Ethiopia (Central Laboratory). Ethiopian Mineral, Petroleum and Biofuel Corporation and Adama Science and Technology University (ASTU) analyzed and interpreted the findings.

3.2. Equipment

Equipment that was employed for the sample preparation and separation test are:-

- Jaw crusher (RoHs53743, Germany) – for size reduction
- Sieve Shaker (RETCH A200, Gemany), -for separating sample to be tested into two size fraction.
- A hand held magnet – for removing ferromagnetic prior to Frantz magnetic test.
- Paint Brush- For cleaning thoroughly the magnetic separator while conducting magnetic test
- Frantz magnetic separator model LB-1 (Central Laboratory of the Geological Institute of Ethiopia).
- A weighing Scale (grammometer).

3.3. METHODS

3.3.1. Sampling of the Kenticha Pegmatite Deposit

Chip samples were taken at four different places inside the lithium bearing mineral rich layer from the spodumene-rich part of the Kenticha pegematite deposit exposed. To prevent contamination, the samples KS1, KS2, KS3, and KS4 were collected using a plastic bag.

When different samples were mixed, quartered, and crushed into a 200 mesh size before being sent for XRD and AAS analysis, the results revealed that the chemical makeup of the samples of as-received sample.



Figure 3.1 collected Sample of Li mineral bearing kenticha pegmatite deposit

3.3.2. Sample preparation for magnetic separation test

Sample were collected from different locations of the Li ore enriched upper part of Kenticha pegmatite deposit to ensure that they represent the entire deposit namely KS1,KS2,KS3 and KS4. These samples were then thoroughly mixed to ensure that they were evenly distributed and homogenously mixed. The mixed sample was then split into smaller portions and crushed using a jaw crusher to obtain the size fraction that was used for Frantz magnetic separation test. The crushed portions were sieved using a sieve shaker to obtain a size fraction that was suitable for magnetic separator testing. It was important to mix the sieved portions thoroughly to ensure that they were evenly distributed. Finally, a representative sample 1Kg was taken from the mixed portion for each size fraction that was used for magnetic separator test.

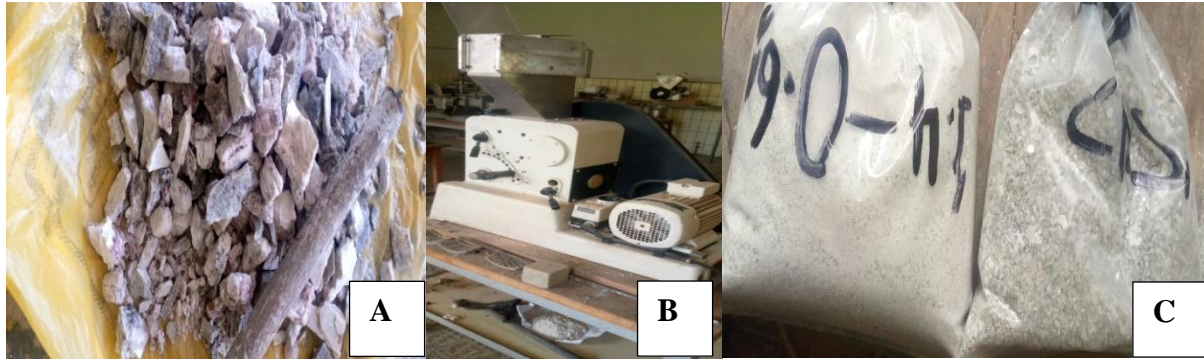


Figure 3.2 A) Homogenously mixed as received samples - ks1,ks2,ks3 and ks4.

B) Shows lab Jaw crusher (RoHs53743, Germany) that was used for size reduction

C) product of jaw crushed and separated in two size fraction sample (0.6mm-1.14mm and >1.14mm-2mm) by using sieve Shaker

3.3.3. Hand Held Magnet

An initial step was taken to eliminate any ferromagnetic material present in the sample. To accomplish this, a handheld magnetic separator was employed for each size fraction. The purpose of this magnetic separation process was to prevent the clogging of grains in the sample when it is later placed into the Frantz apparatus. First, the two size fractions (0.61mm-1.14mm and 2mm-1.14mm) were alternatively spread onto A4 pages. Next, a plastic bag was used to hold a magnet which was then placed over a sample sheet at a short distance. The magnet was gradually moved across the entire sample, causing ferromagnetic minerals in the fraction to adhere to it. The plastic bag was then inverted over the magnet to collect the ferromagnetic minerals. This process was repeated multiple times to ensure removal of any ferromagnetic minerals from both size fractions. The ferromagnetic material was separated and quantified, revealing that the weight of material in the 0.61mm-1.14mm size fraction was approximately 0.62g. However, it was found that the handheld magnetic separator was not effective in removing any ferromagnetic material from the 2mm-1.14mm size fraction.



Figure 3.3 shows the removal of the ferromagnetic mineral before electromagnetic separation test for each size fraction

3.3.4. Experimental Set-up

The selection of process variables took into account the magnetic properties of ore minerals found in the pegmatite deposit and the presence of other gangue minerals in the sample. These factors were chosen after thorough research in different literatures. The recovery and effectiveness of the mineral separator were significantly impacted by these two factors. To carry out experiments, a 2² full factorial design was created using Minitab software.

Table 3.1 Coded and levels of the variables for the Frantz Magnetic separator test

Factors	Unit	Coded symbol	LEVEL 1		LEVEL 2	
Particle size range	mm	MT1	Fine (0.6mm-1.14mm)		Course(1.14mm-2mm)	
electromagnetic intensity		MT2	Current	1A	Current	0.5A
			Voltage	65.2V	Voltage	36V

General full factorial with two factors (particle size fraction, electro magnet strength) and two levels combinations with total number of 4 runs were used to conduct the study.

StdOrder	RunOrder	PtType	Code	feed size fraction	magnetic intensity		
1	1	1	NM4	2mm-1.14mm	High	I	1A
						V	65.2V
2	2	1	NM1	1.14mm-0.6mm	High	I	1A
						V	65.2
3	3	1	NM3	2mm-1.14mm	Low	I	0.5A
						V	35.6V
4	4	1	NM2	1.14mm-0.6mm	Low	I	0.5A
						V	35.6V

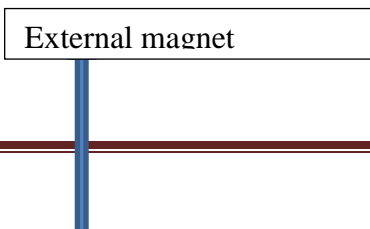
- Number of factors, $f = 2$ and Replicate, $r = 1$
- Number of total test = $2 * 2 = 4$ Table 3.2 Experimental design setup using MiniTab software

During this study by using the Frantz magnetic separator, the variables of feed temperature and feedstock vibration rate were held constant for each trial. The feed rate remained consistent, and the weight of the feed to the electromagnetic separator was measured. A representative sample of 1kg was taken for each size fraction (as shown in Figure 3.1A) from sieved, crushed, and ground ore. The tests were conducted according to the output obtained from minitab software.

Each size fraction's 1kg sample was carefully divided into two equal parts and weighed. For each test, 500g of the sample was used. To initiate the mineral separation process using the Frantz magnetic separator, the sample was carefully poured into the sample holder or feed while

keeping the design variables constant. Prior to starting the process, it was ensured that all voltages were set to zero to prevent any voltage fluctuations or surges. The voltage strength could be adjusted using the controller provided (Fig 3.5B) and the electromagnetic separator was turned on, with adjustments made according to the experiment's run number. The process involved feeding particles through a funnel onto a vibrating tray (as depicted in Figure 3.4) that was placed within a magnetic field. Diamagnetic and paramagnetic particles were deflected in opposing directions, and a mechanical divider was used to separate them while still within the field to prevent recombination. The rate at which particles travel through the field was determined by the longitudinal tray angle and the vibration amplitude.

The dark-colored bin found towards the left was for collecting magnetic grains and the light-colored bin found at the right was for collecting the non-magnetic minerals. Both bins were fixed at the bottom of the fork chute (as shown in Fig shows 3.6A). The magnetic and non-magnetic minerals collected in separate bins were collected in a clean plastic bag for each run of the experiment and weighed by a digital weight scale. Since lithium has no magnetic susceptibility, the nonmagnetic stream was sent for analysis for potential recovery of lithium oxide . Each nonmagnetic stream of the test was sent for AAS analysis. Additionally, both magnetic and nonmagnetic streams were sent for XRD analysis to obtain phase information of both streams.



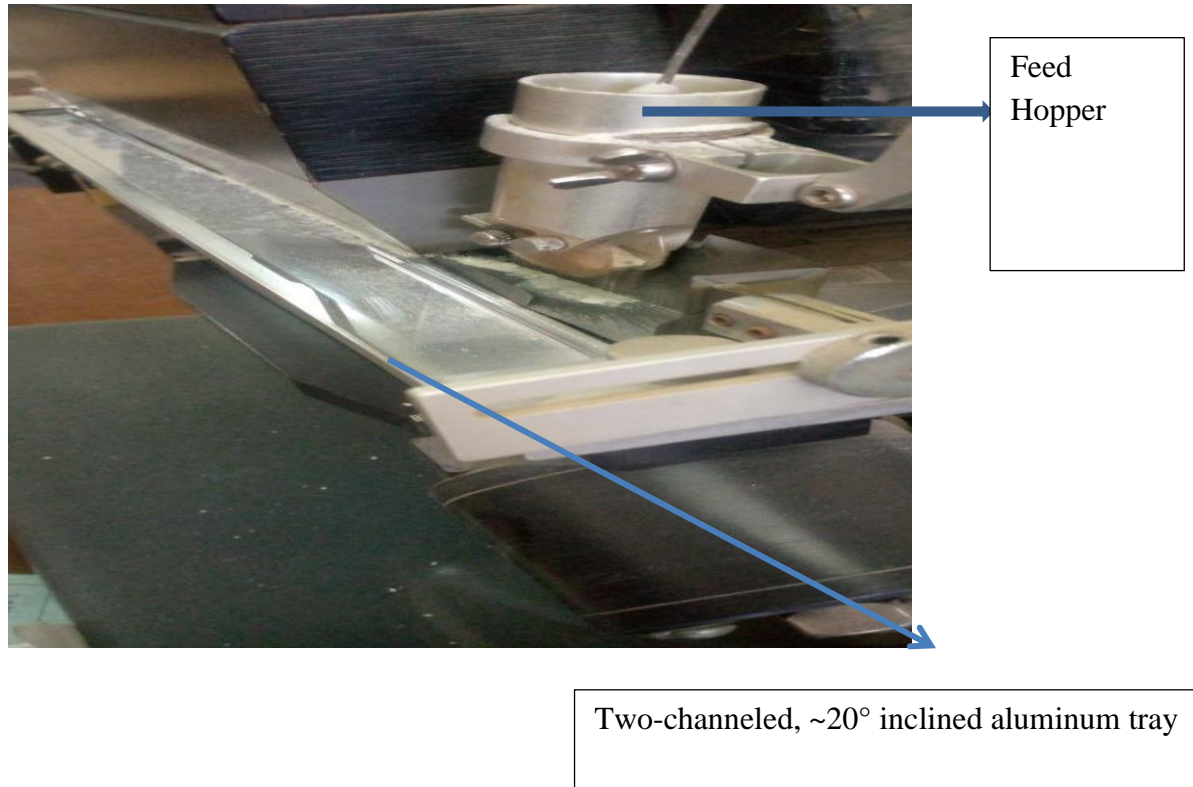


Figure. 3.4 Frantz Magnetic separator and its several components.

The data collected from magnetic testing of a lithium-bearing sample was analyzed using AAS and XRD to determine the effects of two operating variables (feed size range and magnetic strength of the magnetic separator) on two responses: the percentage recovery of Li_2O and the effectiveness of the magnetic separator. In order to optimize multiple responses simultaneously, graphs depicting the relationship between variables and responses were used.

3.3.5 Frantz magnetic separation test

The Frantz Magnetic Separator was used to examine the ideal working parameters and efficiency of the magnetic separator. It was tested to see how effectively it separated paramagnetic minerals from non-magnetic minerals at various amperes and voltages. The Frantz Isodynamic Magnetic Separator was meticulously cleaned from top to bottom, starting with the chute, bolts, aluminum trays, feed, collecting tins, etc. Then each of these parts was painstakingly put back where it belonged. The forward scale at the top and the side of the tilted scale both have scales where the angle of the ramp may be changed, or its tilt angle can be chosen (Fig. 3.5).



Figure 3.5. The electromagnetic separator tilted to angle of chute ~20°

In the subsequent stage, the fork chute and aluminum shield that covered its top were taken and placed so that they could both glide over the ramp's bottom and be fastened with an aluminum bolt (as shown in Fig. 3.5). The aluminum bolt wasn't overtightened because the chute was made of plastic. The next phase involved installing two collection bins in two distinct colors. Non-magnetic minerals were gathered in the light-colored bucket on the right, and magnet grains were recovered in the dark-colored bin on the left. There were two permanent bins at the bottom of the fork chute. Once the bins were securely fastened, a clipping sound could be heard. The springs were grabbed at either end and rotated about.



Figure 3.6. 3.6A) two separation bins attached at the end of the chute to separate non-magnetic minerals and magnetic minerals. 3.6B) the voltage controller that aids in adjusting the voltage provided to the Frantz Instrument according to requirements.

The iron-bearing minerals are separated from nonmagnetic minerals in the bulk sample based on their magnetic susceptibility strength. The weights of the magnetic and non-magnetic streams were measured for each experiment run, and their efficiency was calculated by using formula 3.1.

$$\text{Efficiency (in \%)} = \frac{\text{weight of the collected magnetic material}}{\text{Weight of the total feed material}} \times 100 \dots \text{(Formula 3.1)}$$

For each experiment run, the nonmagnetic stream was analyzed using AAS to determine the percentage composition of lithium oxide (Li₂O). If the feed percentage composition of the target and the target percentage composition in concentrate, as well as the weight of feed and concentrate, are known, formula 3.2 can be used to determine the percentage recovery of the target mineral, as described in Wills, Barry A., and James A. Finch, 2016.

$$\text{Recovery} = \frac{C_c}{F_f} \times 100 \quad \dots\dots \text{(Formula 3.2)}$$

Whereas C=weight of concentrate

c =concentrate assay

F =feed weight

f =feed assay

3.4. Analysis of the variables and responses obtained from the test

The purpose of the study was to figure out the effectiveness of the magnetic separator in eliminating magnetic material from a sample of a rock containing lithium as well as the implications of optimum multiple variables (feed size range and magnetic intensity) to obtain various values of responses (magnetic separator efficiency and Li₂O recovery). The Minitab software was employed for assessing the data from the lab experiment in order to determine the most effective variables. The recovery of Li₂O with regard to feed size range and magnetic intensity has been demonstrated using a mean effect plot, which was also included in the study to analyze the association between the components and response.

4. RESULTS AND DISCUSSION

4.1. Mineralogical Characterization of Samples

The lithium-bearing sample, that were collected from four different exposures labeled as ks1, ks2, ks3, and ks4, was collected from Kenticha LCT pegmatite deposit. The as-received sample were subjected to various analytical methods.

4.1.1. AAS Analysis of the as-received sample

The samples were analyzed AAS analysis using the fusion method and homogenized - samples KS1, KS2, KS3 and KS4.

Table 4.1 Lithium oxide and iron oxide contents of samples from Kenticha LCT Pegmatite

Coded samples	Li ₂ O(%)	Fe ₂ O ₃ (%)
KS1	0.01	0.51
KS2	2.04	0.89
KS3	1.86	0.69
KS4	1.88	1.008

4.1.2. Silicate analysis of sample

After homogeneously mixing the samples KS1, KS2, KS3, and KS4, the resulting composite sample A-B-1 was size reduced using the cone and quartering method. Silicate analysis was performed to examine major and minor oxides, using the LiBO₂ fusion method. For gravimetric, colorimetric, and AAS analysis.

Table 4.2 Silicate analysis results of the composite A-B-1 sample from the kenticha pegmatite deposit

Code	SiO ₂ (%)	Al ₂ O ₃ (%)	CaO(%)	MgO(%)	Na ₂ O(%)	K ₂ O(%)	MnO(%)	Wight of the sample
A-B-1	53.24	28.74	<0.01	3.6	3.36	0.16	0.06	200g

4.1.3. X-ray diffraction (XRD) Response samples

In order to ensure accurate analysis of the lithium-bearing samples (KS1, KS2, KS3, and KS4) using XRD, a meticulous sample preparation process was implemented. The samples were mixed homogeneously by employing the cone and quartering techniques, and then pulverized to a 200 mesh size in EGIL. This ensured that the intensities obtained during analysis reflected the precise structure and composition of the analyzed phases. Subsequently, 200g of each sample was sent to the AASTU material engineering laboratory for analysis. The diffraction pattern of homogenized sample from KS1, KS2, KS3 and KS4 is shown on figure 4.1.

The samples were carefully mixed and homogenized before being subjected to cone and quartering to obtain a representative sample for XRD analysis. The diffraction pattern obtained indicates a significant amount of iron in association with other minerals, as well as notable concentrations of spodumene and silicate minerals such as albite and quartz. (Figure 4.1).

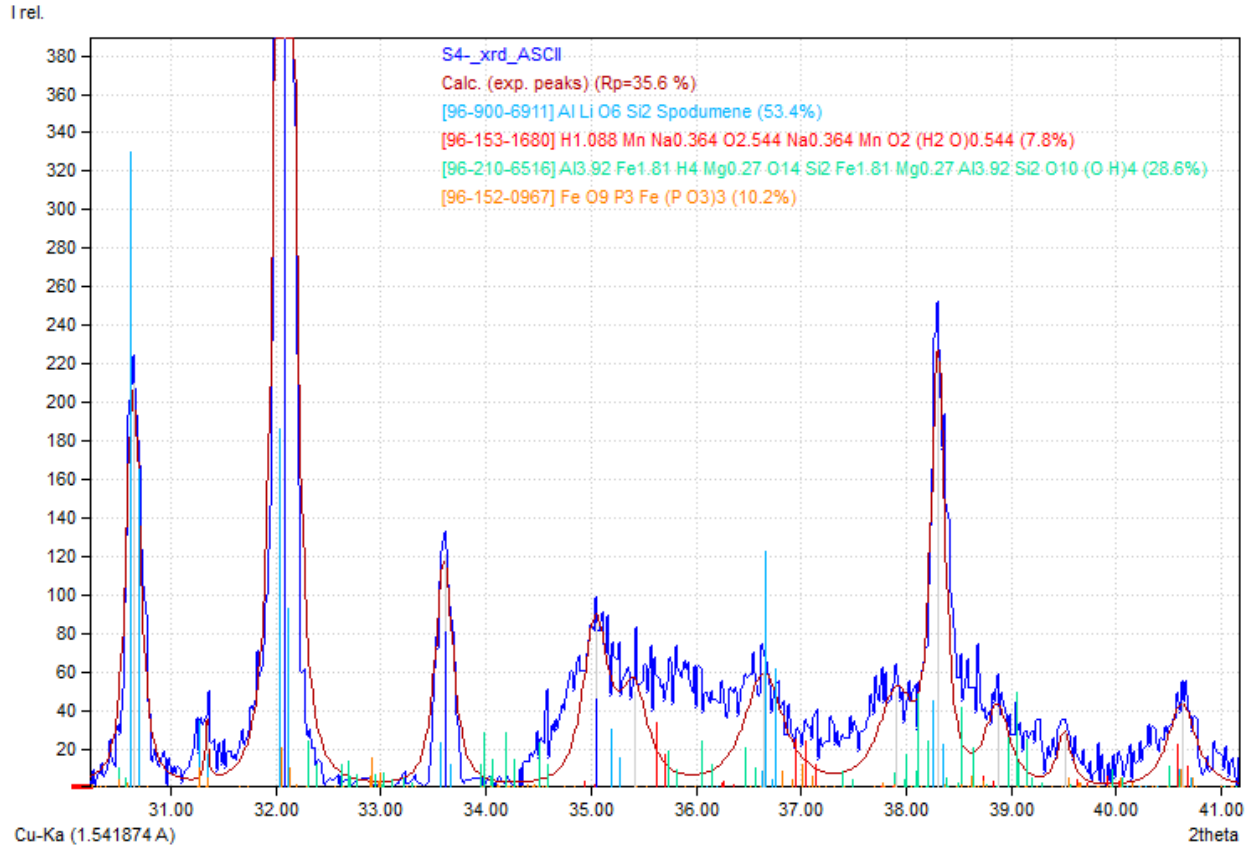


Figure 4.1 The diffraction pattern of homogenized sample from kenticha pegmatite deposit.

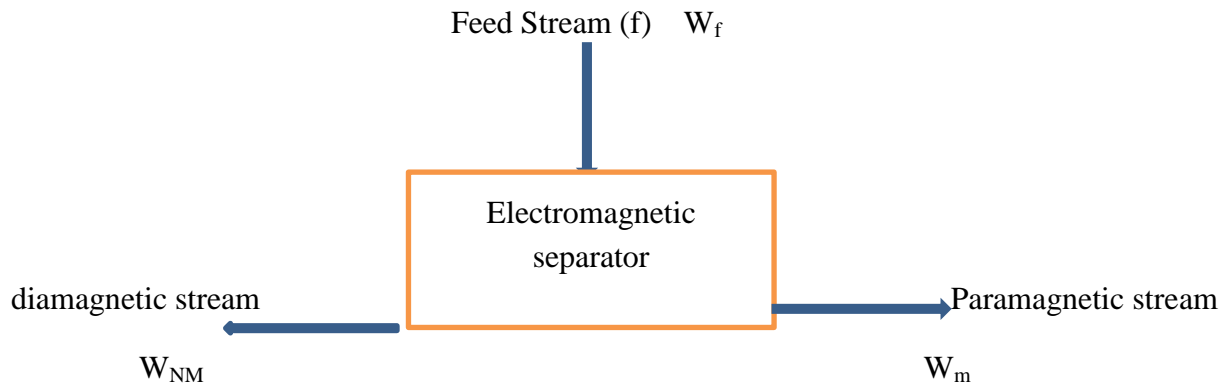
4.2. Frantz magnetic test response

Prior to the magnetic testing, any ferromagnetic material was manually removed from both size fractions using a handheld magnet (shown in Figure3.3). The sample was then subjected to a Frantz electromagnetic test. The two key parameters used to evaluate the test results in this work the recovery of Lithium oxide and the effectiveness of the equipment in separating non-magnetic and iron-bearing minerals.

4.2.1. Efficiency of magnetic separator

The effectiveness of the Frantz electromagnetic separator in separating iron-bearing minerals from the sample was studied. Each test run involved feeding 500g of the sample to the separator, and the magnetic and non-magnetic streams were weighed using a digital weighing scale and recorded.

Figure 5 shows a material balance example for the electromagnetic test, with the naming convention for streams adhered to consistently throughout the tables reporting the data.



Whereas $W_f = W_m + W_{nm}$ $W_f =$ weight of feed $W_m =$ weight of magnet $W_{NM} =$ weight of nonmagnetic

Figure 4.2 Material balance for Frantz electromagnetic separation

Efficiency (Column 5) of magnetic separator on removing magnetic bearing minerals was calculated by

$$Efficiency (in \%) = \frac{W_m}{W_f} \times 100$$

Table 4.3 Weight acquired from every run, in addition to the efficiency of the electromagnetic separator.

Run	Condition	Code	weight of nonmagnetic Stream(g)	weight of magnetic stream(g)	Efficiency (%)
1	Dry	NM4	285.4	207.05	41.4
2	Dry	NM1	297.2	198.66	39.73
3	Dry	NM3	298	199.05	40
4	Dry	NM2	265.6	230.4	46

4.2.2. Recovery of Lithium bearing mineral separated by Frantz magnetic separator

The lithium-bearing samples, namely KS1, KS2, KS3, and KS4, were mixed homogeneously and underwent size reduction using a Jaw crusher (RoHs53743, Germany) and sieved to obtain two size fractions: 2mm-1.14mm and 1.14mm-0.6mm. The test was conducted based on the assigned run number obtained from the Mintab software.

The sample was then passed through an electromagnetic field, and the magnetic and non-magnetic streams were collected separately in plastic bags and weighed. The non-magnetic stream was analyzed using AAS analytical method, while the mineral phase in both the magnetic and non-magnetic streams were analyzed to obtain the mineralogical information of magnetic and non-magnetic stream through diffraction data (XRD).

Table 4.4 Weight obtained in the magnetic and nonmagnetic streams of the separator (W_m and W_{nm}) during each run, along with the percentage composition of lithium oxide (Li_2O) obtained through the AAS fusion analytical technique.

Run	Code	weight of nonmagnetic Stream(g)	Weight of magnetic Stream(g)	Li_2O (%)	Fe_2O_3 (%)
1	NM4	285.4	207.65	1.94	0.35
2	NM1	297.2	198.66	2.36	0.25
3	NM3	298	199.05	1.93	0.25
4	NM2	265.6	230.4	2.22	0.34

To evaluate the efficiency of the magnetic separator in increasing the concentration of lithium-bearing minerals, the percentage recovery of lithium oxide was determined. This involved analyzing ore samples collected from various locations of the deposit (KS1, KS2, KS3, and KS4) and calculating the average percentage composition of the target mineral, which was then used as the feed assay for the separator (Mular, A.L., and R. Poulin, 2002).

The concentrate assay for each run of the experiment was determined by analyzing the percentage composition of Li₂O in the nonmagnetic stream using AAS analytical method (as presented in Table 4.4).

Percentage recovery of the lithium bearing mineral calculated by using the following formula.

$$\text{Recovery} = \frac{C_c}{F_f} \times 100$$

To maintain homogeneity, the feed assay of lithium oxide was determined by taking the average of the lithium oxide present in samples KS1, KS2, KS3, and KS4. This resulted in a lithium oxide assay of 1.55%.

Table 4.5 Weight obtained in the magnetic and nonmagnetic stream of separator (W_m and W_{nm}) during each run, along with the percentage recovery of lithium oxide.

Run	Code	weight of nonmagnetic Stream(g)	weight of magnetic Stream(g)	Li ₂ O(%)	% Recovery of Li ₂ O
1	NM4	459.42	36.9	1.94	71.44
2	NM1	301.35	198.2	2.36	90
3	NM3	331.12	123.61	1.93	74
4	NM2	280	270.183	2.22	76.4

Table 4.6 presents the analysis results of AAS to gain a valuable information on the impact of electromagnetic separation on the concentration of major oxides in each experiment run. The table shows that the separation process did not affect the concentration of major oxide, such as SiO₂, which remained in the concentrate. This indicates that albite, quartz, and other silicates in pegmatite deposits were not influenced by magnetic field in the separator. However, the iron content in test number two was significantly reduced.

Table 4.6 percentage compositions of major oxides (silicon oxide, iron oxide, and Aluminum oxide) in the nonmagnetic stream of the separator during each run of the experiment.

Run	Code	%Si2O	%Al2O3	%Fe2O3
1	NM4	69.12	20.14	0.35
2	NM1	66.25	22.12	0.25
3	NM3	69.98	21.15	0.26
4	NM2	67.89	22.16	0.34

The Result of AAS analytical techniques showed that the Li₂O content of the nonmagnetic stream from the electromagnetic separator test varied based on different combinations of factors, including magnetic intensity and feed size fraction. The test showed that a combination of high magnetic intensity (1A and 65V) and fine feed size fraction (0.6mm-1.4mm) resulted in better recovery of lithium oxide in the nonmagnetic stream compared to the same magnetic field strength with a coarse feed size fraction (as shown in Figure 4.3).

These results suggest that the lithium bearing mineral in the Kenticha pegmatite deposit is liberated at a fine fraction and that magnetic-bearing minerals can be more effectively rejected at a fine size fraction. Additionally, the test showed that the Kenticha LCT pegmatite deposit contains few ferromagnetic minerals associated with the ore minerals of the deposit, which can be removed by handheld magnets for fine size fractions but not for coarse size fractions. The response of the electromagnetic test and handheld magnet demonstrate that the effectiveness of the separator in rejecting ferromagnetic and paramagnetic minerals in the ore is greatly influenced by the feed size fraction.

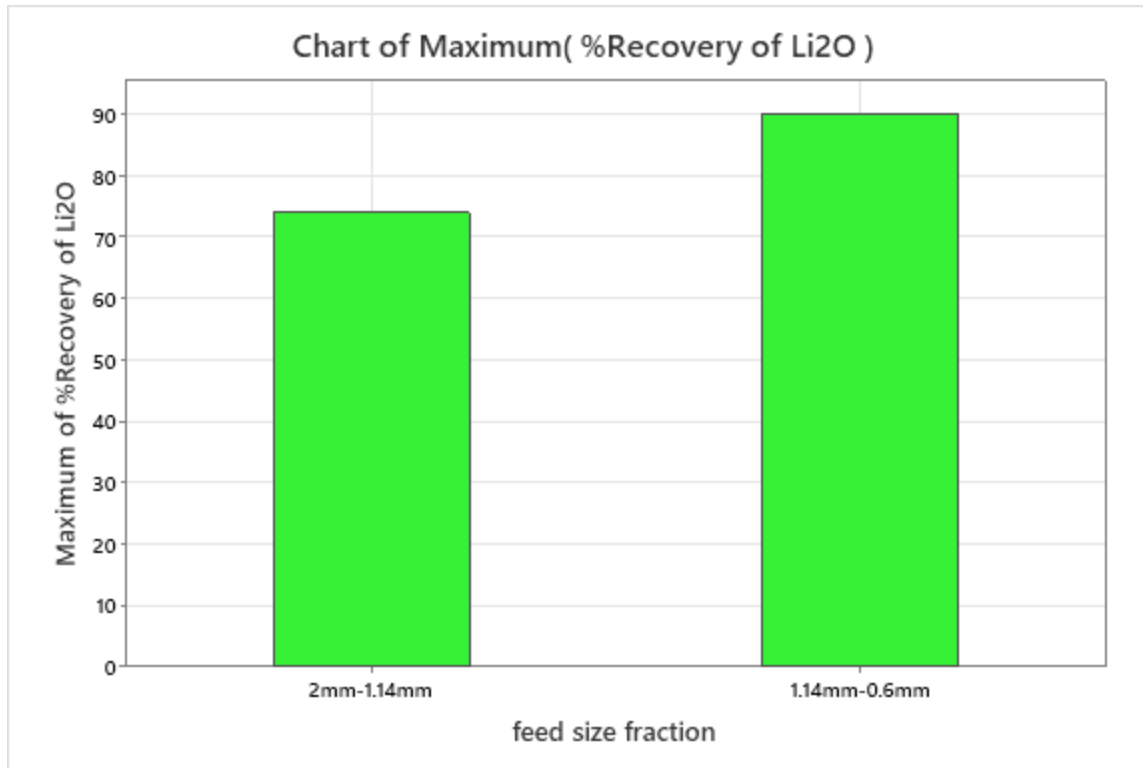


Figure 4.3 Chart of percentage Recovery and Feed size fraction result obtained from analysis of nonmagnetic stream of magnetic separator.

Figure 4.4 Illustrates that the magnetic intensity level employed during the separation process has a substantial impact on the average recovery of Li₂O. The data presented in Table 4.6 reveals a noteworthy decrease in iron-bearing minerals during tests NM1 and NM4, indicating that a high magnetic intensity was utilized. In contrast, tests NM2 and NM3 showed a higher percentage composition of Fe₂O₃ for each feed size fraction when observed to the low-intensity test. These findings suggest that the strength of the magnetic field strength in the separator is a critical factor in improving the recovery of Li₂O.

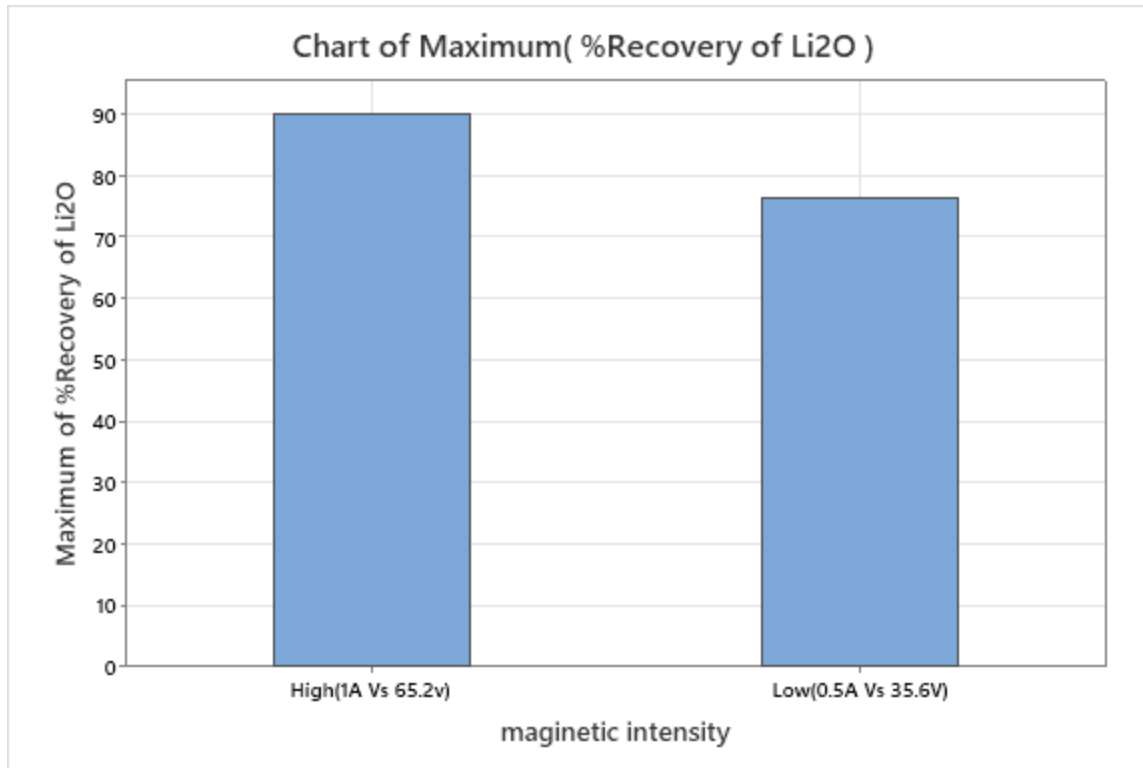


Figure 4.4 Chart of percentage Recovery and magnetic intensity result obtained from analysis of nonmagnetic stream of magnetic separator.

The line plot in figure 4.5 shows the maximum %Recovery of Li₂O and Efficiency of separator for different feed size fractions. The different colors represent the different size fractions. The line plot also indicates that the percentage Recovery of Li₂O and Efficiency of the separator increase as the feed size fraction decreases. This is because at a smaller feed size fraction, lithium minerals are liberated from associated gangue minerals, which allows for more Li₂O to be recovered and the separator to be more efficient. The plot also demonstrates that the percentage recovery of lithium oxide and efficiency of the separator for the fine size fraction increase significantly with increased magnetic intensity, while the coarse size fraction does not exhibit this trend.

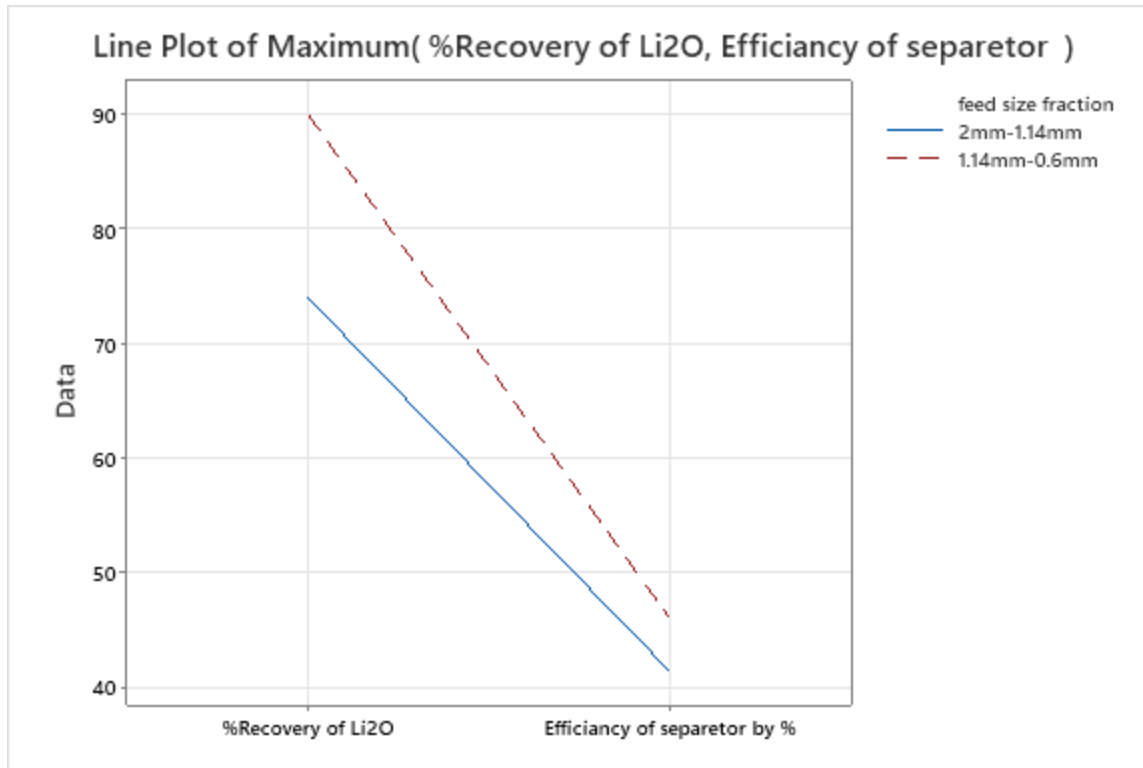


Figure 4.5 Line plot of maximum %Recovery of Li₂O, Efficiency of separator, as the function of feed size fraction.

The line graph in Figure 4.6A illustrates the maximum percentage recovery of lithium oxide based on feed size fractions and high magnetic intensity (1A and 65.2 v). Results indicate that tests conducted with high magnetic intensity for both coarse and fine size fractions yielded different percentage recoveries. Notably, tests carried out with high magnetic intensity and fine feed size fractions resulted in a significantly higher percentage recovery of Li₂O compared to tests conducted with similar magnetic intensity but coarse feed size fractions. The maximum percentage recovery of lithium oxide based on feed size fractions and low magnetic intensity (0.5A and 35.6 v) is presented in Figure 4.6B. The graph demonstrates that feed size fractions have a significant impact on percentage recovery. However, unlike high magnetic intensity tests, feed size differences have no great influence on recovery at low magnetic intensity tests, as observed from the graph.

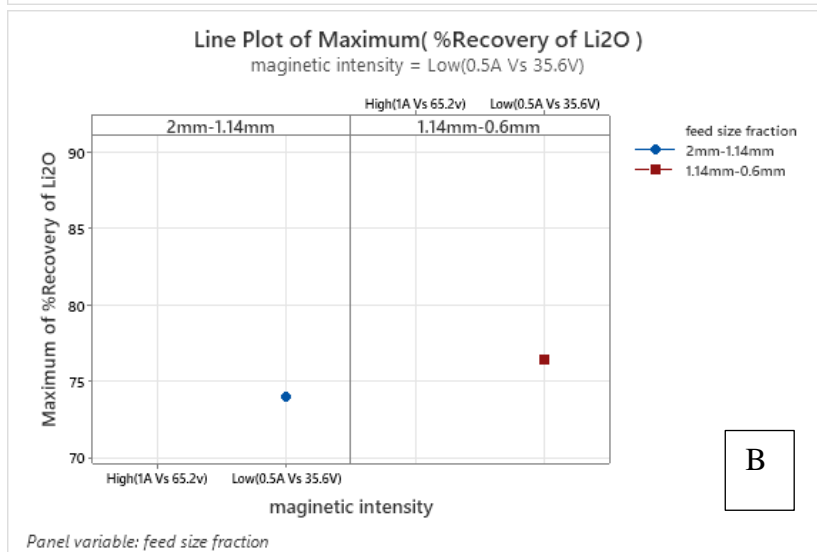
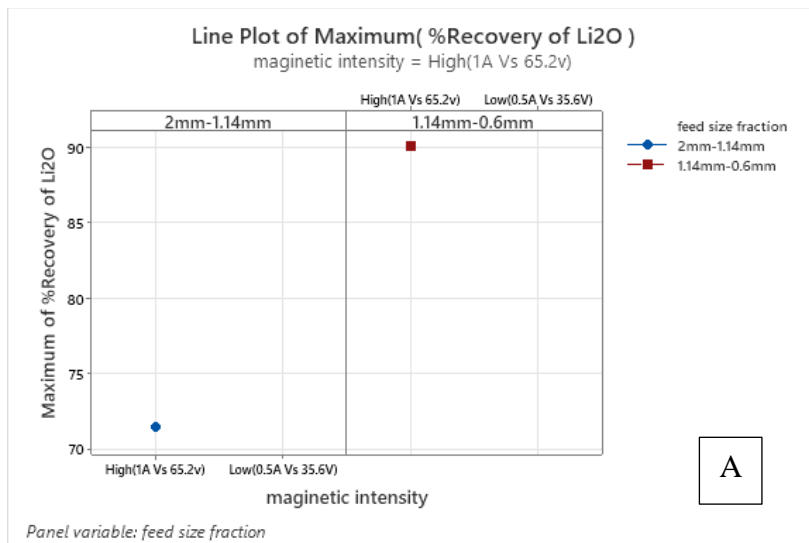


Figure 4.6 A) Line Plot of Maximum (% Recovery of Li₂O) when test conducted at HighMagnetic Intensity and Feed Size Fractions B) Line Plot of Maximum (% Recovery of Li₂O) when test conducted at LowMagnetic Intensity and Feed Size Fractions.

4.2.3 Results deduced from diffraction data (XRD)

The result obtained from Frantz magnetic test was sent **XRD** Analysis to examine mineral phase that reported to magnetic and nonmagnetic stream. The spectrum from XRD analysis for the sample is given Fig 4.7 and Fig 4.8.

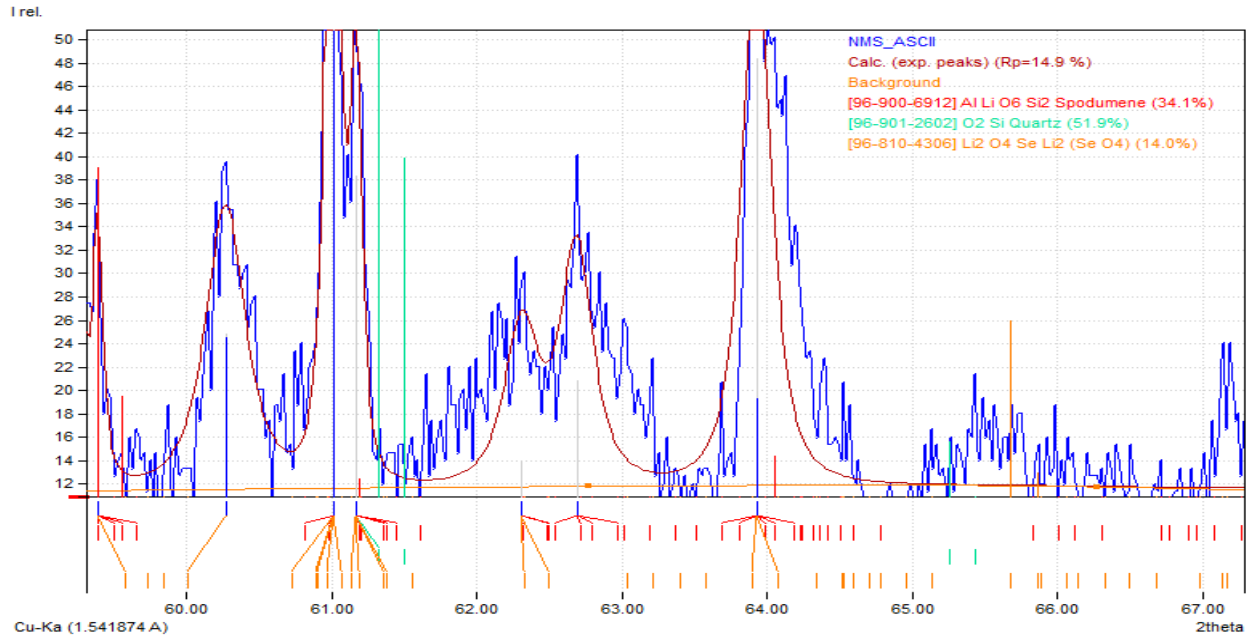


Figure 4.7 the diffraction pattern of nonmagnetic stream of Frantz magnetic separator

After conducting four consecutive tests, an X-ray diffraction (XRD) analysis was conducted on a nonmagnetic stream to identify its mineral phase. The diffraction pattern indicated that the magnetic separator effectively removed the iron-bearing mineral, leading to an increased concentration of spodumene. However, a significant amount of silicate minerals remained in the nonmagnetic stream. Additionally, the diffraction pattern suggested that the magnetic separator was unable to eliminate the entire iron-bearing mineral from the sample. (Figure 4.7).

In the diffraction pattern of the XRD analysis of the magnetic stream obtained from the Frantz magnetic separation test shown in Figure 4.8, it was noted that the iron-bearing and iron minerals were significantly reduced. Nevertheless, spodumene was detected in the magnetic stream, indicating that the magnetic separator employed was not entirely effective. The result suggests the need for a more appropriate magnetic separator to be employed.

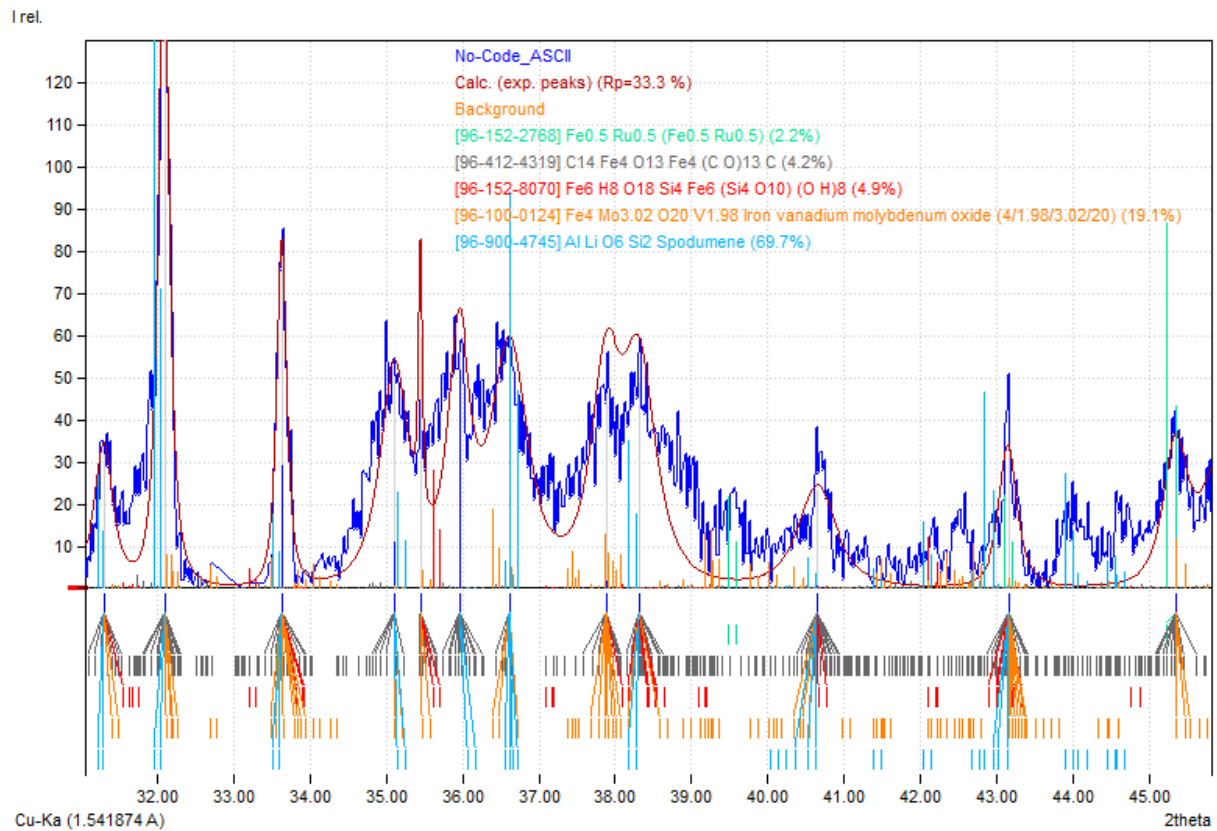


Figure 4.8 the diffraction pattern of magnetic stream of Frantz magnetic separator

4.3. Optimum operating condition for Frantz Dry Magnetic Separation in Eliminating Iron-Bearing Minerals from Ore Minerals of the Kenticha Pegmatite Deposit.

The the study was to explored the impact of magnetic intensity and particle size on the Frantz magnetic separator's ability to eliminate iron-bearing minerals from Li hosting minerals of the Kenticha pegmatite deposit. Additionally, the study sought to determine the optimal feed size fraction and magnetic intensity for improved recovery. Four experiment runs were conducted, and the results were analyzed using various techniques. The non-magnetic stream of the Frantz magnetic separator was found to contain spodumene due to its diamagnetic property.

The results were plotted on graphs, indicating that magnetic intensity and feed size fraction were significant factors influencing the recovery percentage of Li_2O . The analysis result showed that the Frantz magnetic separator's optimal operating conditions for achieving better recovery and separation efficiency of Li_2O were during test run number two, conducted at high intensity (1A Vs 65.2v) and with a fine feed size fraction (0.6mm-1.14mm).

4.3. Statistical Results

Particle size fraction and magnetic field strength were used as independent variables, and separator performance and possible Li_2O recovery were used as dependent variables, in a series of experiments to investigate the efficiency of the separator and potential recovery of lithium oxide (Li_2O). This study determined the main factor influencing the effectiveness and recovery of target minerals in processing operations also the impact of these variables on individual responses. To reduce errors brought on by machinery and human factors, the trials were planned and carried out in accordance with the output of the minitab software. On the graphics bellows are the primary effect plots for the percentage in the feed size fraction and magnetic intensity additionally the interaction effect plots.

The primary effect figure in Figure 4.9 shows that the feed size percentage significantly affects the mean recovery of Li_2O at constant magnetic strength. The plot indicates that Li_2O recovery is increased when smaller sample sizes are fed into the electromagnetic separator. This reveals the significant function that feed size fraction has in Li_2O recovery.

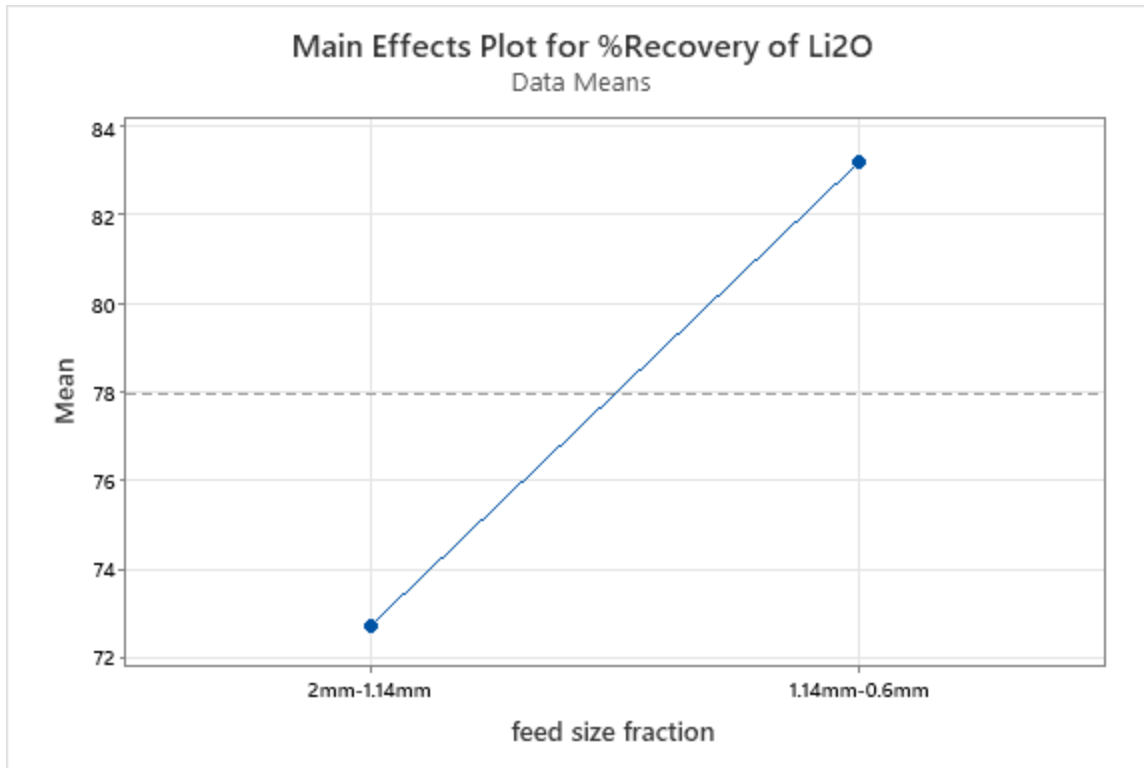


Figure 4.9. main effects plot for percentage recovery of Li₂O and feed size fraction

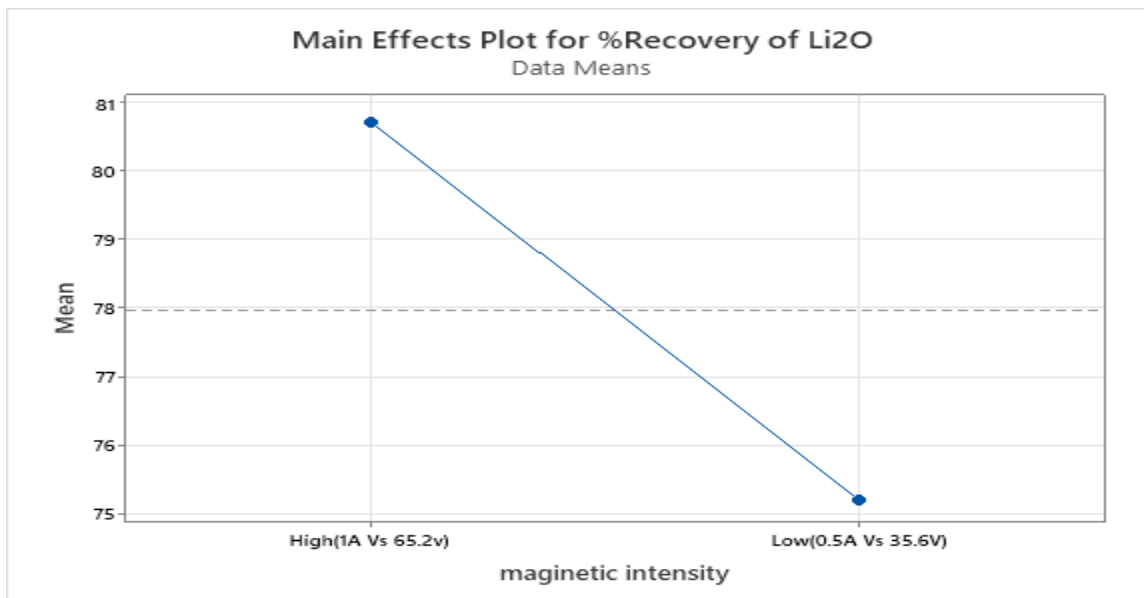


Figure 4.10. main effects plot for percentage recovery of Li₂O and feed magnetic intensity

Figure 4.10 main effect plot reveals that, as feed size fraction remains constant, the magnetic intensity has a significant influence on the average recovery of Li_2O . The plot highlights that conducting tests at a high magnetic intensity (1A vs 65.2v) resulted in a better recovery of Li_2O . This plot suggests that the strength of the magnetic field strength in the separator plays a crucial role in the enhancement recovery of Li_2O .

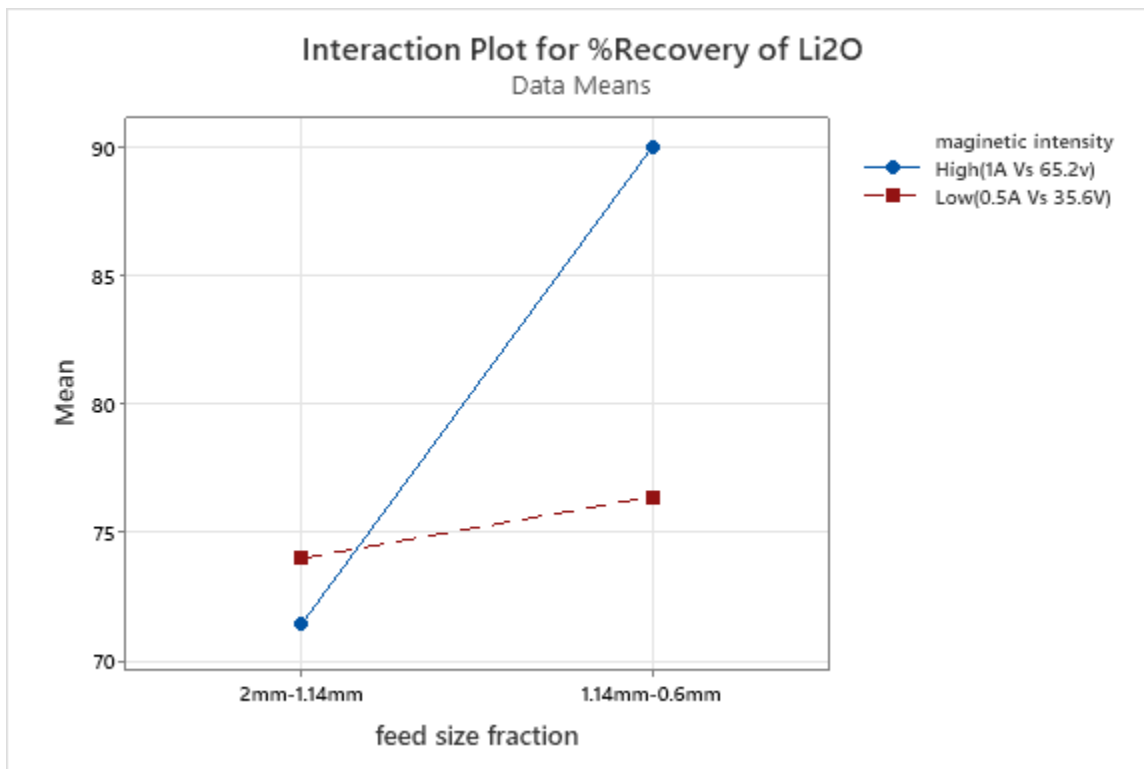


Figure 4.11. Intraction effects plot for percentage recovery of Li_2O as function of feed size fraction and maginetic intensity

As Figure 4.11 shows the percentage recovery of Li_2O as a function of the feed size fraction and the magnetic intensity. The interaction plot shows that the relationship between the percentage recovery of Li_2O and the feed size fraction is different for different levels of magnetic intensity. For example, at a low level of magnetic intensity, the percentage recovery of Li_2O increases as the feed size fraction decreases.

This is because the separator is more effective at separating the Li_2O from the other materials in the feed when the feed size fraction is small.

4.4. Comparison of Magnetic Separation Method with Other Conventional lithium mineral Processing Methods.

4.4.1. Dense media separation (DMS).

Dense medium separation (DMS), one of the most popular techniques in the mineral processing industry, uses a dense medium to separate minerals based on the contrast in their specific gravities (Ferrara, Machiavelli, Bevilacqua, & Meloy, 1994). Dense particles must be suspended in water to provide a medium that can segregate minerals according to their density. Spodumene, a lithium-bearing mineral that is usually found alongside other silicate gangue minerals such as feldspar, mica, albite, and quartz, is often mined using DMS because of its economic feasibility. The specific gravity of the material of interest and gangue minerals dictates the most suitable DMS medium, with ferrosilicon and magnetite typically used during spodumene beneficiation from pegmatite deposits. Before further concentration by flotation, DMS is frequently employed as a preconcentration stage to remove gangue minerals associated with the target.

4.4.2. Froth flotation

Lithium-containing minerals, such as spodumene, are usually treated using froth flotation. This concentration technique, which is frequently used to extract lithium-hosting minerals from pegmatite deposits, is based on the surface properties of minerals. When the liberation size or specific gravity difference between the target minerals and gangue is too small for successful gravity separation, froth flotation is especially advantageous for processing challenging or low-grade ores (Tadesse B., 2019). According to their hydrophobicity, minerals are selectively separated using the froth flotation separation method (Gibson, M. Aghamirian, and T. Grammatikopoulos, 2017). Magnetic separation methods may be applied either before or after the flotation technique, based on the mineralogy and iron concentration of the lithium-bearing mineral (Aghamirian, 2012). Magnetic separation is capable of helping separate the magnetic materials out of the slurry to ensure they are able to float independently.

4.4.3. Magnetic separation method

The magnetic separation method is a crucial beneficiation technique for lithium-containing pegmatite ores that are mixed with gangue, such as iron-bearing minerals, which are challenging to separate from lithium minerals through other processing methods like DMS and/or flotation. This method is also extensively used to refine the concentrate of lithium minerals, making it suitable for use in manufacturing ceramics and glass. There are two types of magnetic separators in the mineral processing industry based on the condition of the feed: dry and wet magnetic separators. The study utilized dry Frantz Electromagnetic separator to explore the potential of magnetic separation for lithium hosting kenticha pegmatite deposit by eliminating ferrous and ferrous silicate from the sample. The results showed an improved recovery of Li_2O and better separator performance (Figure 4.6 & Figure 4.5).

Additionally, it was observed that the size fraction of the feed had a significant effect on the recovery of lithium-bearing minerals, with fine fractions showing better recovery than coarse size fractions. The intensity of the magnetic separator also influenced the effectiveness and recovery of the separation process, with high-intensity tests (1A & 65v) showing better performance in rejecting ferrous minerals and increasing the percentage composition of Li_2O than low-intensity tests (0.5A & 35v).

Although the test results offered valuable insights into the separation process and the effectiveness of the separator, the study faced challenges in finding a suitable magnetic separator. Furthermore, a lack of design and manual information for electromagnet separators found in CEGLI made it difficult to estimate magnetic intensity and strength for a given current and voltage. Consequently, these limitations could have impacted the experimental results, and it is essential to consider them in future studies.

4.4.4. Plant practices in the beneficiation of lithium bearing ores from pegmatite rock by magnetic separation method .

The mineralogy of the ore, which includes both the target minerals and gangue minerals, heavily influences the beneficiation and treatment methods adopted by processing plants. To improve concentrate quality and decrease the amount of iron-bearing silicates like amphibole and tourmaline before flotation, many facilities processing lithium-bearing minerals use magnetic separation into their beneficiation process flow. The plants that follow are examples of those that incorporate magnetic separation into their process flow sheets.

4.4.5.1. The Greenbushes, Australia

The Greenbushes deposit encompasses pegmatite masses with convex forms that connect along the strike and dip and exhibit mineralogical zoning. According to Partington GA, McNaughton NJ, and Williams IS (1995), the predominant minerals present in the main Greenbushes pegmatite encompass quartz (28%), spodumene (26%), albite (23%), K feldspar (20%), tourmaline (1%), mica (1%), and apatite (0.5%).

The two separate processing facilities at Greenbushes Lithium Operations produce technical-grade lithium concentrate and chemical-grade lithium concentrate, separately. In order to produce these lithium concentrates, the ore is subjected to gravity, heavy media, flotation, and magnetic separation. The final separation of tourmaline from spodumene is accomplished using a WHIMS. This machine operates with a field strength of 0.9 tesla and uses a matrix of soft iron balls with a 6mm diameter to achieve ideal separation performance. Fe₂O₃ content of less than 0.1% can be achieved with just one pass (Bale, M.D., & May, A. V., 1989).

4.4.4.2 Bernic Lake Lithium operation, Canada

More than hundreds various minerals, including spodumene, lepidolite, amblygonite, petalite, and eucryptite, are present in the diversified pegmatites in the Bernic Lake region of Manitoba (Agharmirian, 2012). Dense media separation, amblygonite pre-flotation, magnetic separation, and flotation constitute a few of the steps in the beneficiation process at Bernic Lake. Gravity separation is used to eliminate tantalum-containing materials following low intensity magnetic separation to Reject iron bearing minerals from the fine size fraction of the feed.

Table 4.6 Comparison of Magnetic Separation, Froth flotation and Gravity (DMS) methods

Methods	Advantage	Disadvantage
Magnetic Separation method	<ul style="list-style-type: none"> ✓ Can be used to remove significant amounts of gangue minerals containing iron from the concentrate. ✓ Can be used to produce high grade lithium concentrates which can be used for ceramic application. ✓ Is a relatively simple and inexpensive ✓ Magnetic separations process is cost effective and environmentally friendly operation 	<ul style="list-style-type: none"> ✓ May not be effective for removing all gangue minerals. ✓ May not be suitable for all types of spodumene ores. ✓ May produce a concentrate with high iron content.
Froth flotation	<ul style="list-style-type: none"> ✓ Can be used to separate lithium minerals from a variety of gangue minerals based on surface property contrast of target and gangue mineral. ✓ Can be used to produce high-grade lithium concentrates. ✓ Is a relatively efficient process. 	<ul style="list-style-type: none"> ✓ May be more expensive than magnetic separation. ✓ May need the use of chemicals and complex reagent scheme that can be harmful to the environment. ✓ May produce a concentrate with a high water content.

Gravity method(DMS)	<ul style="list-style-type: none"> ✓ Can be used to separate lithium minerals from a variety of gangue minerals even the gangues have close specific gravity difference. ✓ Is a relatively simple and inexpensive process. ✓ Does not require the use of chemicals. ✓ It used at coarse size rejection which saves operating cost down processing. 	<ul style="list-style-type: none"> ✓ May not be effective for removing all gangue minerals. ✓ May not be suitable for all types of spodumene ores. ✓ The target minerals and the gangue (such as iron-bearing silicates like amphibole) typically do not separate from one another because to their tiny SG differences.
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4.5. Selecting the appropriate magnetic separator for lithium ores of the Kenticha LCT pegmatite deposit.

Magnetic separators are available in various shapes and sizes, depending on their operating conditions and intensity of magnetic field. They can be categorized as either wet or dry, depending on how the material is fed into the separator. Additionally, magnetic separators can be classified as high or low based on the strength of the applied magnetic field. The following figure shows various classifications of magnetic separators.

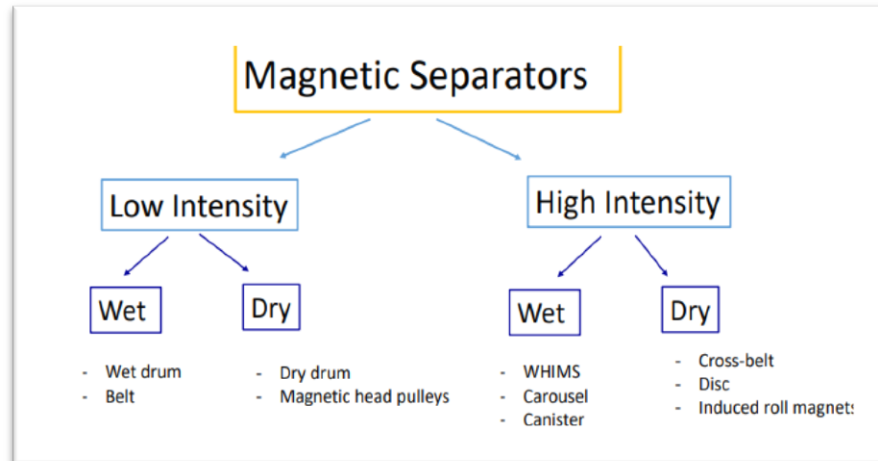


Figure 4.12. Classification of magnetic separators commonly known in the mineral processing industry (A.Wills,James A. Finch,, 2016)

Table 4.7 provides information on the advantages, disadvantages, and uses of wet and dry magnetic separators. Additionally, it highlights two types of separators, which are widely used in the mineral processing industry. Mineralogical analysis of the LCT pegmatite deposit Kenticha shows that the deposit contains significant iron-bearing minerals that could compromise the purity of the concentrate if not eliminated during the beneficiation process.

Table 4.7 shows the features of dry magnetic separator and wet magnetic separator

Features	Dry Magnetic Separator	Wet Magnetic Separator
Applications	Nonmagnetic minerals are removed from the ferrous metal	Iron bearing mineral separation from slurries and liquids
Advantage	<ul style="list-style-type: none"> • less expensive to run, additional applications are attainable, and doesn't need something to wet it • Widely used for course size feed 	<ul style="list-style-type: none"> • produce less dust emissions during operations • used to improve feed particle size oversight, leading to in a better separation method when feed size is fine.
Disadvantage	Can produce dust, requires a dry environment as well as it can be difficult to clean.	Operating costs are higher, a wetting agent is essential, and a smaller number of applications are possible.
Commonly used separators	Include both low- and high-intensity drum and roll devices.	Include drum-type machines with both low and high intensities.

During this study magnetic tests were conducted using the Frantz electromagnetic separator, and it was found that the highest recovery of Li_2O was achieved at high intensity and fine feed size fraction. As the feed size fraction became finer, the minerals were less or not affected by gravity force, resulting in non-magnetic minerals being reported to magnetic streams and a decline in target mineral recovery (as shown in Figures 4.6A and 4.6B).

This work's analytical report showed that at the feed size fraction of 0.6mm to 1.14 mm, there was significant recovery of lithium oxide (as shown in Figure. 4.8), which also provided information on the liberation of lithium minerals. As the size fraction got finer, the mineral recovery improved. The test results indicate that upgrading of lithium minerals by the magnetic method is effective at fine size fractions, since at that size range it ensures the liberation of lithium-bearing minerals. From various reports in the literature, it is recommended that incorporating WHIMS with other conventional processing methods such as DMS, flotation, and desliming will yield better recovery and purity of lithium concentrate if it is employed in the future.

5. CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

This work was successful in rejecting iron-bearing minerals associated with deposits and enhancing lithium oxide percentage composition in nonmagnetic streams. The magnetic test was conducted using a Frantz dry magnetic separator to examine the effectiveness for magnetic separation method for LCT pegmatite deposit and optimum operating conditions that resulted in better recovery of Li_2O .

- The recovery and effectiveness of the mineral separator were significantly impacted by Feed size fraction and magnetic intensity.
- It was observed that better efficiency of the separator obtained efficiency was under 50 % for all test conducted it indicated inefficiency of Frantz separator for this particular deposit.
- It was observed that better recovery of Li_2O was achieved at runs conducted at high intensity (1A and 65V) and at a fine size fraction of feed (1.4 mm–0.6 mm) with a lower concentration of iron oxide (Fe_2O_3) than the feed assay of ferrous minerals. Under these conditions, the concentration assay result of lithium oxide (Li_2O) was 2.36 percent. This is a significant improvement over the recovery of Li_2O from the untreated ore, whose feed assay was 1.55(%).
- The project findings provide valuable insights into the potential of magnetic separation as a viable technique for upgrading lithium-bearing minerals as well as magnetic separation techniques has Potential of enhancing the percentage recovery of Li_2O and purity of concentrate by incorporating a suitable magnetic separator into the beneficiation circuit for The Kenticha LCT pegmatite deposit.

5.2. Recommendations

The research project has highlighted the potential of using magnetic separation as an auxiliary technique for upgrading lithium-ore minerals. It is recommended to conduct pilot-scale magnetic testing using WHIMS and taking into account other factors besides feed size fraction and magnetic intensity, as well as increasing the level of both feed size and magnetic intensity, which can help better estimate the optimum operating conditions of the magnetic separator. Additionally, it is recommended to use analytical techniques such as ICP-MS to analyze response variables more accurately. It is also suggested that the plant consider incorporating magnetic separation as part of future beneficiation methods for lithium minerals. This could potentially lead to more efficient and cost-effective methods for upgrading lithium-bearing minerals.

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