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BENEFICIATION METHOD AND IRON REMOVAL FROM FELDSPAR ORE

S. Tinesha*[1], I. Ismail[1], A. Roshaida[1], O. Anuar[1] and C. H. Voon[2]

[1] Mineral Research Centre, Minerals and Geoscience Department Malaysia, 31400 Ipoh, Perak, Malaysia.

[2] Institute of Nano Electronic Engineering (INEE), Universiti Malaysia Perlis (UniMAP), Jalan Kangar-Alor Setar, Seriab 01000 Kangar, Perlis, Malaysia.

corresponding: tinesha@jmg.gov.my

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Abstract— The sodium feldspar ore from an undisclosed area in Malaysia contains 0.22% potassium oxide and 9.46% sodium oxide, categorizing it as high-quality feldspar ore. It is inapplicable due to high iron content. This research proposed a new effective technique with a two-step process using a magnetic separator and chemical to eliminate iron from feldspar ores. An analysis was performed on the characteristics of sodium feldspar ore, and optimum parameters were identified. The sodium feldspar experienced a substantial decrease in iron oxide concentration, dropping from 2.25% to 0.38%, significantly reducing iron oxide content. This feldspar concentrate fulfils the specifications of the glass and ceramics sectors. The efficient and eco-friendly extraction of feldspar offers a promising method for the sustainable usage of feldspar minerals.

I. Introduction

Feldspar minerals include high concentrations of potassium, sodium and alkali metals making them essential to produce glass, ceramics, and various other industries [1-3]. The beneficiation operations produce a significant amount of feldspar slime that contains a high concentration of minerals including iron. This hinders its ability to be used effectively [3]. The iron content of feldspar poses a significant barrier during its processing [1]. Physical and chemical techniques, including magnetic and gravity separations, flotation and various leaching may be employed to eliminate impurities from non-metallic ores. However, in practical circumstances, magnetic separation offers a cost-effective approach for removing magnetic elements such as iron from ores, stemming from its simple operation, renewability and environmental friendliness. The flotation and leaching methods are costly and pose environmental risks, though they can achieve higher iron removal. There is an increasing trend to integrate magnetic and flotation or leaching methods to attain cost-effective operation and adhere to environmental regulations [17].

There are two primary techniques for eliminating iron content include magnetic separators and attrition scrubbing. Based on [16], the authors posited that magnetic separators effectively remove the magnetic minerals and feldspar to a large extent. In the dry method, a double-disc magnetic separator (DDMS) separates ferrimagnetic minerals, including magnetite, pyrrhotite, and titanomagnetite. DDMS has been demonstrated to be a successful method for lowering iron content in feldspar, resulting in improved quality for use in many industries. This is particularly beneficial in dry places with limited water supplies and low enrichment costs.

The separation performance of a DDMS depends on the parameters of the magnetic separator and the properties of mineral particles, such as particle size distribution, magnetic properties and degree of dissociation. Previous studies have shown that it effectively segregates particles ranging from 75μm to 25mm and has shown notable success in separating minerals with moderate paramagnetic properties [18]. However, in the processing of these ores, the prior removal of strongly magnetic minerals such as magnetite and fine iron impurities is usually demanded to avoid matrix clogging. While drum magnetic separators are utilised in the beneficiation of magnetic ores, they are not very efficient in removing small amounts of highly magnetic minerals and fine iron scraps from non-metallic ores. This is because the magnetic force in these separators is insufficient to achieve higher amperes. For this reason, a wet high-intensity magnetic separator (WHIMS) has become a technique for recovering fine, low-magnetic iron minerals with a maximum magnetic field strength of 21A [6, 7].

Rocha *et al*. [8] showed that the WHIMS method can efficiently remove 30% of the iron content from the tailings of the processing plant in Minas Gerais, Brazil. For an extended period, attrition scrubbers have been in the mineral processing of specific ores. However, they have recently been recognized as particularly useful in soil remediation operations. This is because they can generate intense shear forces on particle surfaces, effectively freeing surface pollutants [9]. The reserve of feldspar mineral reported by the Department of Mineral and Geoscience stated 13,665.5 million metric tonnes in Malaysia [10]. In the current scenario, most companies are exporting raw samples without processing causing a decrement in production, normally the raw sample costs RM120.00 per tonne. The process's feldspar can be up to RM400.00 per tonne, eventually improving the economic growth in Malaysia.

Thus, this study utilised a sample from an unidentified location in Malaysia. The primary objective is to reduce the iron content by employing a two-step process involving a magnetic separator (DDMS and WHIMS) and attrition scrubbing. This process aims to supply feldspar of optimal quality that satisfies the requirements of industries, such as glass and tile production.

II. Sample Preparation

The feldspar ore was obtained from an unidentified location in Malaysia. The material was crushed with a Jaw Crusher and processed with a Cone Crusher. The material was subsequently blended uniformly and partitioned (using cone and quartering techniques) into several bags for head assay, mineralogical, and particle size examination. The samples were ground with variation time to find the optimum particle size. Following the grinding process, both the grinding medium and samples were extracted from the mill. The resulting ground samples were then separated using dry and wet screening methods. A 10g pellet sample was submitted for elemental analysis using the Shimadzu XRF-1700 model. The milled sample, with particle sizes ranging from -300 + 45um and -600 + 45um, underwent a series of extraction such as a double-disc magnetic separator (DDMS), a wet high-intensity magnetic separator (WHIMS), and attrition washing using sulfuric acid. The measurement of minor elements in Fe_2O_3 using ultraviolet-visible (UV–VIS) spectroscopy. The brightness test was conducted by the CM-2500D Spectrophotometer by Konica Minolta, following the ASTM E313-73 standard.

III. Results and Discussion

A. Determination of Oxide Elements by X-ray Fluorescence (XRF)

X-ray fluorescence (XRF) analysis was employed to determine the primary constituents in the sample. The XRF analysis showed that the feldspar sample consists of SiO_2 (69.9%), Al_2O_3 (16.5%), Na_2O (9.46%) Fe_2O_3 (0.84%), K_2O (0.22%) and MnO (0.02%). The total amount of the feldspar raw sample is 81.27%. Since the Na_2O content is 9.46% greater than K_2O (0.22%), this particular feldspar is categorised as sodium feldspar.

B. Grindability Study

The liberation processes were conducted sequentially, with grinding times ranging from 5 to 13min. The tests were conducted to mitigate the risk of excessive grinding of the sample, which can result in a reduction in particle size. The cumulative passing graph in Figure 1 illustrates the particle size distribution of the feldspar sample. The grinding process lasted from 5 to 13min, during which the cumulative sample passing through the size range of (-600 + 45)µm increased from 31% to 54%. This suggests the presence of particle agglomerates [11]. However, it took less than 7min of grinding to get a particle size of 10% of 45µm. After grinding for more than 9min, the cumulative sample increased by around 10%, suggesting that the sample became slime. Additional grinding led to a reduction in the specific surface area. The conglomeration of particles could be attributed to mechanical activation resulting from extended grinding [12].

According to these findings, the ideal duration for grinding was determined to be 7minutes. Out of the whole material, 40% had a size smaller than 500µm (d50), and 71% had a size smaller than 2100µm (d80). The choice of grinding duration is critical for two reasons: Firstly, to facilitate the separation of iron oxide from other minerals it is linked with, and secondly, to avoid the production of undersized particles caused by excessive grinding. Furthermore, the act of eliminating the slimes, which are materials that are smaller than the desired size, would result in an escalation of the expenses associated with mineral processing [12]. A previous study by Junxiong and teams, large amounts of slime posed a potential hazard to the surrounding water sources and resulted in optimal processing conditions with 2hr of ball milling to achieve 4.1µm [3]. Compared to this study, our feldspar is brittle, and 7min selected for the grinding procedure.

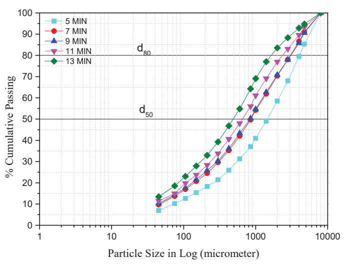

Figure 1: Cumulative passing of particle size distribution analysis at different grinding times

C. Double-Disc Magnetic Separation (DDMS)

Dry magnetic Separation is the process of separating magnetic particles from nonmagnetic particles or relatively strong magnetic particles from relatively weak magnetic particles [13]. From the magnetic separation test, the 1kg sample was tested into 3 categories, which are 0.2A, 0.4A and 0.6A. The sample sizes (-600 + 45)µm and (-300 + 45)µm were fed for the separation. Following the process of magnetic separation, both the raw sample and the non-magnetic sample were subjected to analysis to determine their iron content. The iron content in particles with sizes of -600 + 45µm and -300 + 45µm was significantly reduced by approximately 67% and 60% respectively, in terms of Fe_2O_3.

Additionally, the Fe content declined to 0.52% and 0.63% for the -600 + 45µm and -300 + 45µm samples respectively. Therefore, it can be inferred that the extraction of iron content was greater in particles with a size of -600 + 45µm compared to particles with a size of -300 + 45µm. The reduced particle size of feldspar allows for greater contact area with contaminants and causes an increment in the surface area. A previous study by Fan Yi and the team investigated the trajectory of siderite particles deviating from that of quartz particles reduces with an increase in particle size [5]. As a result, increased particle size (500µm) has a negligible effect on the centrifugal force acting on particles by using a dry high-intensity drum magnetic separator. As a conclusion, both particle sizes were subjected to WHIMS to remove the contaminants, primarily iron (Fe).

D. Wet High Intensity Magnetic Separation (WHIMS)

WHIMS can recovery of fine, weakly magnetic iron minerals. It is evident that the innovative prowess of wet separators notably surpasses that of their dry counterparts [14]. The sample size of -600 + 45µm underwent WHIMS from 2A to 12A. The Fe content in the non-magnetic sample reduced dramatically from 0.52% to 0.33% for a sample size of -600 + 45µm. When the particle size decreases from (-300 + 45)µm, the Fe content decreases by approximately 50%, from 0.63% to 0.30%. This finding indicates that there is a higher tendency for iron to be removed from samples with lower diameters of (-300 + 45)µm. With a wet high-intensity magnetic separator, the separation selectivity of magnetic force to magnetic particles on the surface improves and more entrained particles are released from the magnetic deposits; these particles go into the non-magnetic product and improve its mass weight. However, excessive rinsing water consumption produces an increasingly negative effect on the performance, namely, deterioration in the Fe_2O_3 grade and iron removal rate of the non-magnetic product, as a result of the improved hydrodynamic resistance acting onto particles and the increased number of fine magnetic particles going into the non-magnetic product [17]. A minor enhancement in iron content reduction was seen because of reducing the particle size during the WHIMS process.

E. Attrition Scrubbers

An attrition scrubber is a method used to remove impurities from materials through a process of friction and abrasion. Attrition scrubbers are utilized in the mineral processing of specific ores to apply intense shear forces on particle surfaces, thus releasing surface impurities of microcrystalline graphite, hence improving its quality before flotation performance [15]. In the ongoing experiment, the sample underwent the scrubbing procedure at a pH of 4, with sulphuric acid being used as a pH regulator. Following 10min of vigorous cleaning, the undesired chemicals were successfully isolated from the feed sample. The sample underwent a magnetic separation test, yielding iron content percentages of 0.26% for Fe and 0.38% for Fe_2O_3, for a sample size of (-300 + 45)µm.

F. Colour Measurement

Table 1 displays the levels of whiteness and weight percentage of various powders during the beneficiation procedures. The level of whiteness is generally consistent with the iron content of the powders, indicating the crucial influence of iron-containing impurities on the optical characteristics of the powders [3]. The comparison of colour and Fe (%) content between the treated feldspar. The variable "L" represents the degree of brightness or darkness, with values ranging from 0 (black) to 100 (white) [5], as displayed in Table 1.

Table 1: Comparison of colour Fe_2O_3 (%) content on the sample size (-300 + 45)µm

SAMPLE SIZE	-300µm	-300µm	-300µm
IMAGE	 DDMS	 DDMS > WHIMS	 DDMS>WHIMS> ATTRITION SCRUBBING
IRON CONTENT Fe (%)	0.63	0.30	0.26
IRON CONTENT Fe_2O_3 (%)	0.90	0.43	0.38
BRIGHTNESS, L (L* MEASURED IN FIRED PIECES AT 1200°C)	58.465	71.74	73.57

Based on the observation, there is a significant difference based on the iron content. Additionally, it is evident that the treated sample, after undergoing the scrubbing process, exhibits a brightness level of 73.57% and contains a minimal iron concentration of 0.26%. In comparison to Junxiong and other teams, the present feldspar demonstrated a higher brightness percentage of approximately 73.57% compared to 58% [3].

IV. Conclusion

This work presents a two-step experimental approach to the separation of iron from feldspar. The method involves the use of magnetic separators (DDMS and WHIMS) and attrition scrubbing. Impurity is the primary determinant influencing the whiteness of feldspar. The optimal processing conditions include 7min of ball milling, wet and dry milling process and recommended use of sulphuric acid as a pH controller in the attrition scrubbing process. This method is suitable for sample sizes ranging from -300 to 45 µm and may effectively decrease the iron content to 0.26%. The results were provided by the examination of colour measurements achieved a brightness of 73.57%, with a minimum iron content (Fe) of 0.36%. The initial molar content of Fe_2O_3 was decreased from 2.25% to 0.38%. Accordingly, the sodium feldspar powder of superior quality, with 9.68% $Na_2O + K_2O$ and 0.38% Fe_2O_3, satisfies the feldspar requirements for glass and ceramics. Scaling up the cost-effective recycling of high-quality concentrates from slime enables the sustainable use of feldspar resources.

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