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RECOVERY OF IRON MINERAL FROM INDONESIAN BAUXITE RESIDUE

PEROLEHAN MINERAL BESI DARI RESIDU BAUKSIT INDONESIA

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ABSTRACT

Bauxite residue, a solid waste discharged during alumina extraction, is a hazardous material. Its disposal leads to a serious environmental issue although it contains valuable matter such as titanium, silica, rare earth elements, and high iron content (20-60%). This work aims to improve the recovery of iron content within the bauxite residue using three methods, namely direct magnetic separation, roasting followed by magnetic separation, and reduction followed by magnetic separation. Coal as a reductant and Na_2CO_3 and Na_2SO_3 as fluxes were used in the reduction process. The result of the study reveals that the direct magnetic separation produces iron concentrate with the Fe content of 53.69% and a recovery of 26.72%, while the roasting process at 900˚C and magnetic separation produces a concentrate of 54.57% Fe with a recovery of 37.33%. The best method was by reduction and magnetic separation process using 4% of Na_2CO_3 producing iron concentrates with a content of 63.53% Fe and recovery of 74.73%.

Keywords: bauxite residue, iron concentrate, iron mineral recovery, magnetic separation, roasting.

ABSTRAK

Residu bauksit merupakan limbah padat yang dibuang pada saat ekstraksi alumina. Karena limbah ini merupakan bahan berbahaya dan beracun, pembuangannya dapat menimbulkan masalah lingkungan yang serius. Di sisi lain, residu bauksit mengandung bahan berharga seperti titanium, silika, unsur tanah jarang, dan kandungan besi yang tinggi (20-60%). Penelitian ini bertujuan untuk meningkatkan perolehan kembali kandungan besi menggunakan tiga metode, yaitu pemisahan magnetik langsung, pemanggangan diikuti pemisahan magnetik, dan reduksi diikuti pemisahan magnetik. Pada proses reduksi, sebagai reduktor digunakan batubara serta Na_2CO_3 *dan* Na_2SO_3 *sebagai fluks. Pemisahan magnet secara langsung menghasilkan konsentrat besi dengan kandungan 53,69% Fe dengan perolegan sebesar 26,72, sedangkan proses pemanggangan pada suhu 900˚C dan pemisahan magnetik menghasilkan konsentrat mengandung 54,57% Fe dengan perolehan sebesar 37,33%. Metode terbaik adalah proses reduksi dan pemisahan magnetik menggunakan fluks* Na_2CO_3 *4% yang menghasilkan konsentrat besi dengan kandungan 63,53% Fe dan perolehan sebesar 74,73%.*

Kata kunci: residu bauksit, konsentrat besi, perolehan kembali mineral besi, pemisahan magnetik, pemanggangan.

INTRODUCTION

Bauxite residue is a by-product of the Bayer process for producing alumina from the bauxite. The world alumina production reaches 140 million tons per year (Bray, 2022). On the average, for every 1 metric ton of alumina production, 1–1.5 metric tons of bauxite residue is produced, so the resulting bauxite residue can reach more than 120-170

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million metric tons per year. Considering that the alumina industries in the world have been available since 1800s, the amount of bauxite residue that has been buried in the stockpile is very large, around 4 billion tons (Wang *et al.*, 2019). Recently, alumina refinery plants were established in Indonesia and produced around 2.2 million tons per year of bauxite residue. In the future, this product will increase by adding the production capacity of existing plants as well as the new ones. The bauxite residue has extreme alkalinity, with a pH of more than 11, posing a significant environmental threat. The impact is very worrying because its ability to pollute the soil and cause air pollution around the disposal site. Consequently, the appropriate treatment methods are essential to address these environmental concerns and enable the effective utilization of bauxite residue. Generally, the main mineral content of bauxite residue is hematite, goethite, rutile, silica, and alumina, and a small amount of rare earth elements or REEs (Archambo and Kawatra, 2021; Jin *et al.*, 2021). The composition of the bauxite residue varies depends on the type of the bauxite ore processed into the alumina. In the Bayer process, the valuable elements such as iron (Fe), aluminum (Al), titanium (Ti), and rare earth elements (REEs) are not extracted so they remain in the bauxite residue. The iron content in bauxite residue is quite high, varying between 20 – 60% depending on the processed bauxite ore (Paramguru, Rath and Misra, 2004). Indonesian bauxite contains around 30-40% iron oxide, aluminum, silica, and valuable rare earth elements, especially scandium and neodymium.

It is reported that the utilization of bauxite residue is still limited, namely around 3 million tons per year and is used as an additive for cement production (Archambo and Kawatra, 2021). Massive utilization efforts are starting to speed up, as indicated by many research results on the use of bauxite residue as raw material for building materials (Liu, Yang and Xiao, 2009; Hertel *et al.*, 2020; Ke *et al.*, 2022) and other industries. According to Archambo and Kawatra (2021), bauxite residue has been viewed as a potential source for steel, titanium, aluminum, and REEs industries. Several studies have demonstrated the possibility of improving the concentration of iron minerals obtained from bauxite residue through the adoption of physical beneficiation techniques. In the study conducted by Rai *et al.* (2019), the bauxite residue samples were subjected to a combined hydro-cyclone and magnetic separation process. The results demonstrated a successful rise in the iron content of the samples, with the Fe_2O_3 content rising from 52% to 70% and a recovery of approximately 80%. Li *et al.* (2014) introduced a circulating superconducting magnetic separation to recover iron without the previous reduction process, which yielded low-grade iron content. The effectiveness of this technique is heavily dependent on the magnetic field gradient that is applied. A microwave route study attained concentration with ~47% grade, 88% recovery at 72% yield (Agrawal, Rayapudi and Dhawan, 2019). The reason of lower recovery due to the iron exists in the form of hematite and goethite which have weak magnetic as a result a higher magnetic field is required (Kong *et al.*, 2022).

Attention to the mineral content of iron in bauxite residue as a raw material for steel has been growth. The process begins by separating the iron minerals first and/or continuing using reduction/solid-state reduction and/or smelting at high temperatures (Agrawal, Rayapudi and Dhawan, 2018). The literature studies stated that the processes are required to be carried out on bauxite residue, namely the solid state reduction process and smelting (Borra *et al.*, 2016). The solid-state method reduction of the bauxite residue is carried out with the solid or gas-reducing agents, producing Fe_3O_4 or Fe metal which can be directly used to produce metals with or without magnetic separation. So far, this process has not been commercialized, due to the low iron content, high alkali content, fine particle size, and high water content.

Studies on the direct reduction process for iron extraction from bauxite residue have been conducted. The bauxite residue is mixed with a reducing agent and flux-forming pellets that are then reduced at a certain temperature under reducing conditions. The reduction process using plasma H_2 as a reducing agent has yielded >60% Fe grade that is ideal for steel industry feeds (Bhoi, Rajput and Mishra, 2017; Samouhos *et al.*, 2017). This process takes place at a relatively low reduction temperature. However, the plasma generator requires special handling. Gostu, Mishra and Martins (2018) developed a gas-based reduction method for converting hematite in bauxite residue to magnetite at 540°C for 30 minutes employing a mixture of CO, CO2, and N_2 gases. They recovered 98% of the magnetite in the magnetic fraction, with the grade of magnetite at 60%. The lower grade of magnetite was caused by nanometer-scale agglomerations, which could be linked to the substitution of Fe^{+3} by Al^{+3} and Ti^{+3} in the cation lattice. This substitution was supported by STEM image and Mössbauer spectroscopic analyses. Other process was conducted by roasting the bauxite residue at 550-700ºC before separating the iron using low-intensity magnetic separation (Jin *et al.*, 2021), but the iron grade and recovery were only 57.25 and 65.22% respectively. The low iron grade is because some of the magnetite generated re-oxidized to hematite. While suspension magnetization roasting−magnetic separation was proposed to separate the iron minerals. The optimum parameters were as follows: 650ºC of roasting temperature, a 20 minutes of roasting time, a 20% CO concentration, and particles with a size less than 37 µm accounting for 67.14% of the roasted product. The total iron content and iron recovery of the magnetic concentrate were 56.71% and 90.50% (Wang *et al.*, 2022). Another study was a semi-industrial experiment of suspension magnetization roasting for the separation of iron minerals from bauxite residue to result in the recovery and the grade of iron in the iron concentrate was 95.22 % and 55.54 %, respectively (Yuan *et al.*, 2020) with the optimum parameter process roasting temperature 520°C, a mixed reduction gas concentration ($CO+H_2+N_2$) 40%. Low iron grade was due to the conversion of goethite to magnetite (Liu *et al.*, 2020; Zhou *et al.*, 2023).

An alternative method for enhancing iron extraction from the bauxite residue involves optimizing the phase transformation of hematite to magnetite via the incorporation of chloride, sulfate, and carbonate ions (Li *et al.*, 2014; Wei *et al.*, 2021). The study conducted by Zhu *et al.* (2012) investigated the utilization of sodium carbonate in the magnetic separation reduction roasting process for high-red mud. The results show the iron concentration of 90.87% and the total recovery rate of 95.76%. In a more recent study by Ding *et al.* (2020), the authors compared the outcomes of red mud extraction with and without the addition of 10% sodium sulfate in the reduction roasting process. The addition of sodium sulfate led to an increase in iron grade and recovery, with the values arising from 68.26% to 83.74% and 92.78%, respectively. This finding demonstrates that the presence of salt in the reduction roasting procedure has the potential to enhance both the iron content and iron recovery.

Despite the abundance of research examining reduction roasting to extract iron from bauxite residue, there is a remain regarding a challenge in the high quality of iron products, except for the reduction process, which involves the addition of additives. By employing four phases of the magnetic separation process, this study seeks to enhance the magnetic separation procedure. In addition, an experiment was conducted to assess the transformation of goethite into hematite through a variation of the roasting temperature, without including a reduction process. Adding the sulfate and the carbonate salts as additives to a reduction procedure constituted the following experiment. The success of a process is determined by iron content and product recovery.

METHODOLOGY

The method in this research was to find a suitable process for converting goethite to magnetite in the Indonesian bauxite residue by direct separation, roasting, and reduction processes followed by magnetic separation. Variations in roasting temperature were evaluated. The obtained Fe product could then be used as an iron concentrate or as a source of iron-making/sponge iron.

Materials

The bauxite residue used in this study was derived from an alumina refinery in West Kalimantan province of Indonesia. The as-received sample is pulverized in the laboratory ball mill for 30 minutes. The milled powder was further sieved below 100 µm and oven-dried overnight at 105°C to remove the surface moisture. The mineralogical composition of residue bauxite was determined using X-ray diffraction (XRD). The chemical composition of the bauxite residue is carried out using X-ray fluorescence (XRF). The coal was used as a reductant (passing 0.25 mm), with composition as follows: fixed carbon of 35.73%, volatile matter of 30.66%, ash of 26.90%, and moisture of 6.72%. Sodium carbonate (Na_2CO_3) Merck, limestone ($CaCO_3$), and sodium sulfate (Na_2SO_4) Merck were used as an additive. The product of the roasted and reduced bauxite residue was characterized by XRD and XRF.

Magnetic Separation

Magnetic separation process used in this study consists of a four-stage closed-loop process starting from the rougher, followed by the scavenger, cleaner, and recleaner as shown in Figure 1. It was used for the optimation separation of un-roasted bauxite residue. The Wet High Flux Magnetic Separator (WHFMS) was used during the experiment. The amount of sample is 5000 g. The feed material was subjected to rougher magnetic separation at 4,700 Gauss. The concentrate obtained from the rougher, scavenger, and tailing stages of re-cleaner referred to as Ro Conc, Scav Conc, and Re-clean tail, respectively, are then combined and put into the cleaner magnetic separator. This step is carried out to facilitate additional processing at a significantly elevated magnetic field intensity of 4,700 Gauss. The concentrate obtained was subsequently utilised as the feed for the re-cleaner magnetic separator. The concentrate acquired from the Re-cleaner magnetic separator was designated as the final concentrate (referred to as "final con"). Subsequently, the tailings derived from the rougher stage (referred to as Ro tail) and the cleaner stage (referred to as Cl tail) were introduced into the scavenger magnetic separator for treatment under a magnetic field intensity of 5,000 Gauss. The resulting tailing was in the form of final tailing.

Roasting and Magnetic Separation

The bauxite residue was roasted for 60 minutes at different temperatures of 650, 750, 900, and 1000°C in a rotary kiln under a nitrogen atmosphere and equipped with a vessel for collecting the product. This temperature variation is adopted from a study of Cornell and Schwertmann (2003) which states that oxidation and reduction process take place within the temperature range of 600 to 950°C. The transformation of goethite phase to hematite phase starts from 550°C. The roasted product was ground to reduce the particle size to P90 at 75 microns. The ground roasted sample then was treated with magnetic separation to obtain the iron concentrate and tailing. The process of magnetic separation is carried out in only one stage of the 4 stages in circuit Figure 1, namely rougher. While the scavenging, cleaner, and recleaner stages were not carried out, it is assumed that the phase transformation process from goethite to hematite has been converted perfectly.

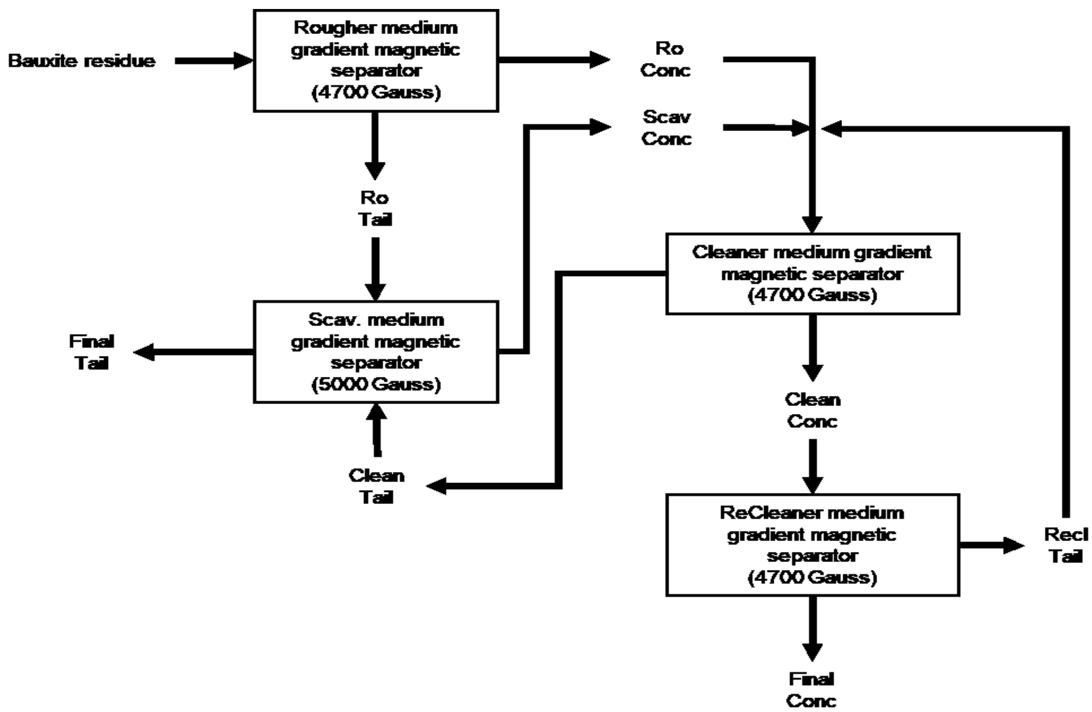


Figure 1. The scheme of magnetic separation of the un-roasted and roasted bauxite residue.

Reduction and Magnetic Separation

In the reduction process, the bauxite residue was agglomerated by mixing 8% coal as a reducing agent, and additives, namely sodium carbonate and sodium sulfate with a percentage 2-4%, then dried and reduced in a rotary kiln at a temperature of 1050°C for 2 hours. The selection of the salt dosage is based on the findings of previous research conducted by Zhu *et al.* (2012) and Ding *et al.* (2020) and adjustments were made to the quantity of salt dosage employed. The reduced calcine was ground to reduce the particle size to P90 at 75 microns and separated using a magnetic separator (Figure 2).

The recovery and total Fe grade of iron concentrate were the key points of this study. The iron concentrate grade was obtained from chemical element analysis, and the recovery was calculated by equation (1).

Recovery: $\frac{b\times y}{a\times w}$x100%................................ (1)

Where b is the Fe grade of the iron concentrate, a is the Fe grade of the feed material, y is the yield of the iron concentrate.

RESULTS AND DISCUSSIONS

Characterization of Raw Materials

The mineral and chemical compositions of bauxite residue were analyzed using quantitative XRD, chemical, and microscopy. Figure 3 shows the major mineral phases present in the bauxite residue are goethite (FeO(OH) 34.43%, hematite (Fe_2O_3) 13.29%, quartz 31.1%, sodalite ($Na_8(Al_6\ Si_6\ O_{24})Cl_2$) 16.03% as a desilication product (DSP), formed by reaction of activated reactive silica content of liquor Bayer process. In addition to the mineral iron, there were gibbsite, and illite as the minor phases. The reactive silica needs to be considered for a further process of REE extraction.

The XRD result is in line with the results of microscope analysis (Figure 4) which revealed the presence of magnetite, characterized by a brownish gray color, high relief, isotropic properties, and a grain size ranging from 0.03 to 0.22 mm. The magnetite grains were predominantly observed as individual particles although some of them had undergone partial conversion to hematite, resulting in the formation of a lamellar replacement texture. Hematite exhibits a light grey coloration and possesses a medium-low relief. It displays anisotropic properties and exhibits a deep red reflection. Hematite is found in locations where magnetite would typically be present. Goethite is a mineral characterized by its cloudy gray appearance, exhibiting medium-low relief. It is anisotropic in nature and displays a deep reflection brown color. The grain size of goethite typically ranges from 0.03 to 0.27 mm. It commonly exhibits a coliform texture and is predominantly found as individual grains. Furthermore, non-metallic minerals are also present.

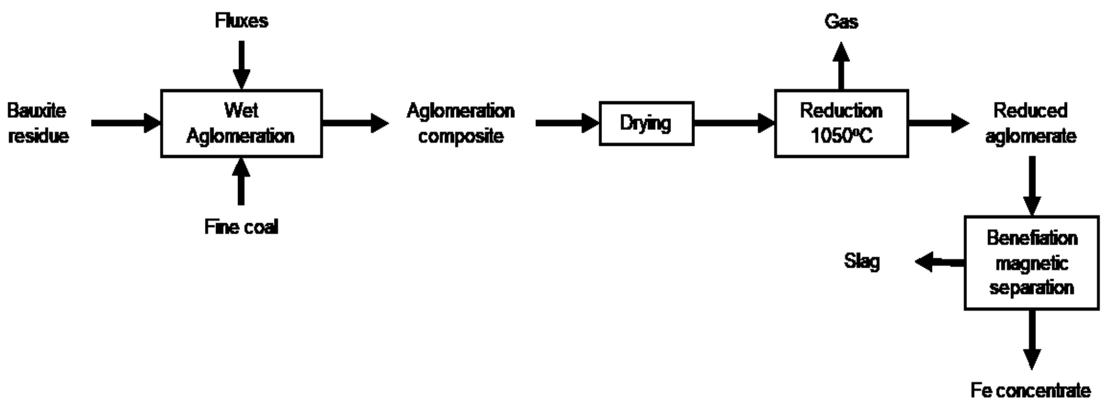


Figure 2. Flow diagram for the reductive of bauxite residue, followed by magnetic separation process.

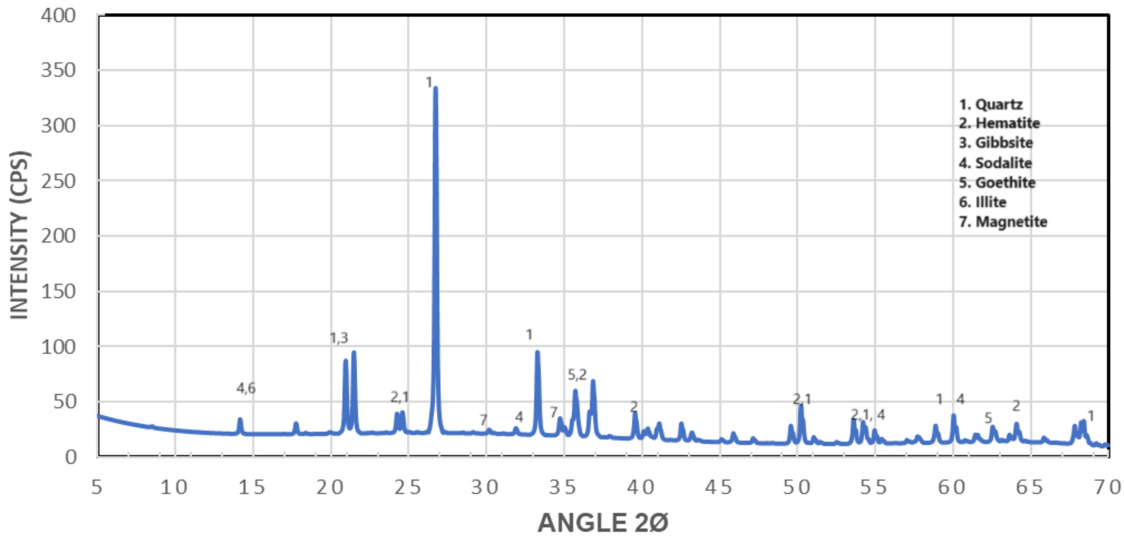
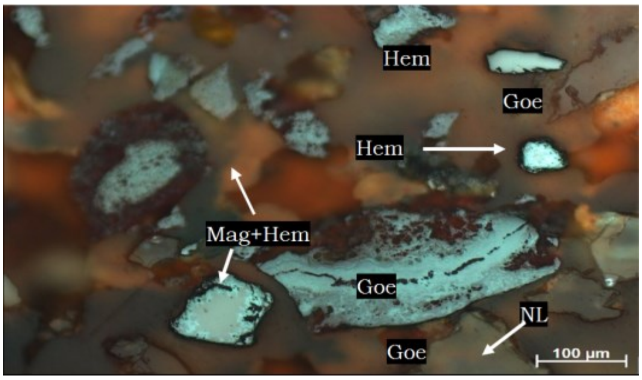


Figure 3. Bauxite residue XRD diffractogram.



Note: Goe= Goethite; Hem= Hematite; Mag= Magnetite; NL= Mineral non-metal

Figure 4. Photomicrograph of bauxite residue polishing sample

Chemical composition of major and minor elements in bauxite residue was analyzed using XRF technique, as depicted in Figure 5. It shows that the Fe_2O_3 content and the total Fe content in the bauxite residue were found to be 37.37% and 26.16% respectively. Additionally, the bauxite residue contained 23.98% SiO_2 and 15.89% Al_2O_3. The Fe_2O_3 composition of bauxite residue in Indonesia exhibits similarities to those of Spain (Alcoa, 37.5%), Turkey (Seidisehir, 36.94%), USA (RMC, 35.5%) (Patel and Pal, 2015), and India (HINDALCO, 36.26%) (Agrawal, Rayapudi, Dhawan, 2018). The metal oxide content of residue bauxite such as MgO, P_2O_5, MnO, and K_2O were < 0.21%, while CuO, Cr_2O_3, ZrO_2, ZnO, PbO, SrO, and BaO compounds were <0.04% (Figure 5).
However, it should be noted that the mineral types present in these residues are not identical. The dominant characteristic of bauxite residual raw material has weak magnetic property, which necessitate the utilization of high-intensity magnetic techniques for efficient separation from non-magnetic constituents.

Direct Magnetic Separation

Magnetic separation of the bauxite residue without any previous treatment, samples was carried out following the process flow diagram in Figure 1. The intensity of the magnetic separator used was 4700-5000 Gauss. The iron mineral in bauxite residue was separated under high magnetic intensity. Figure 6 shows the content of the oxide present in the concentrate and tailings of the bauxite residue after magnetic separation process.

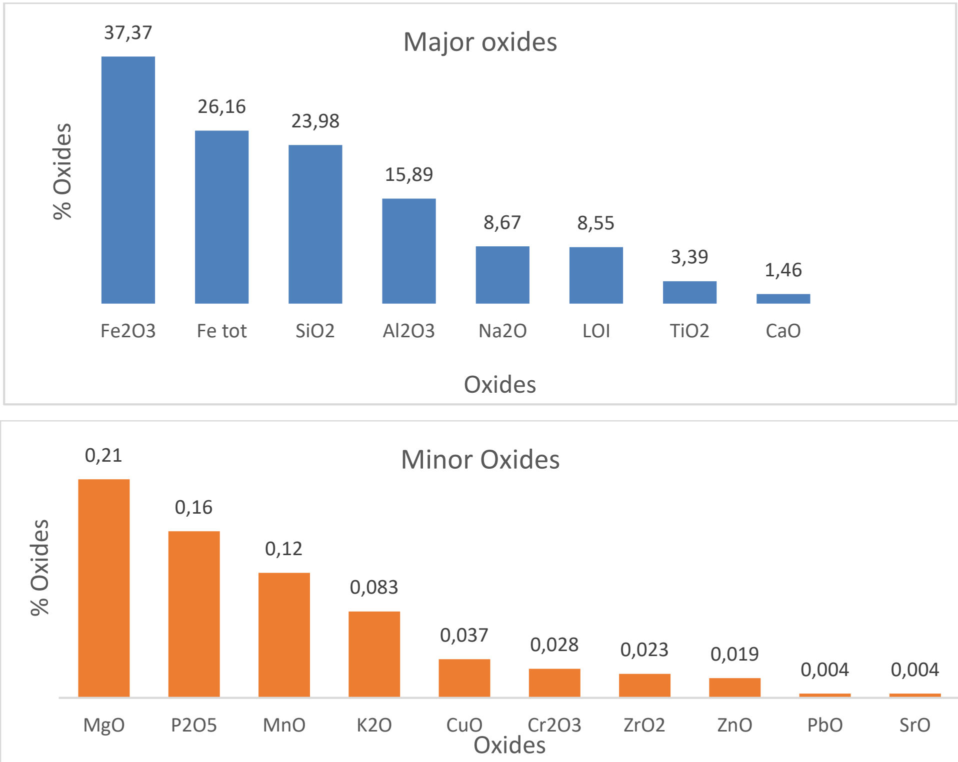
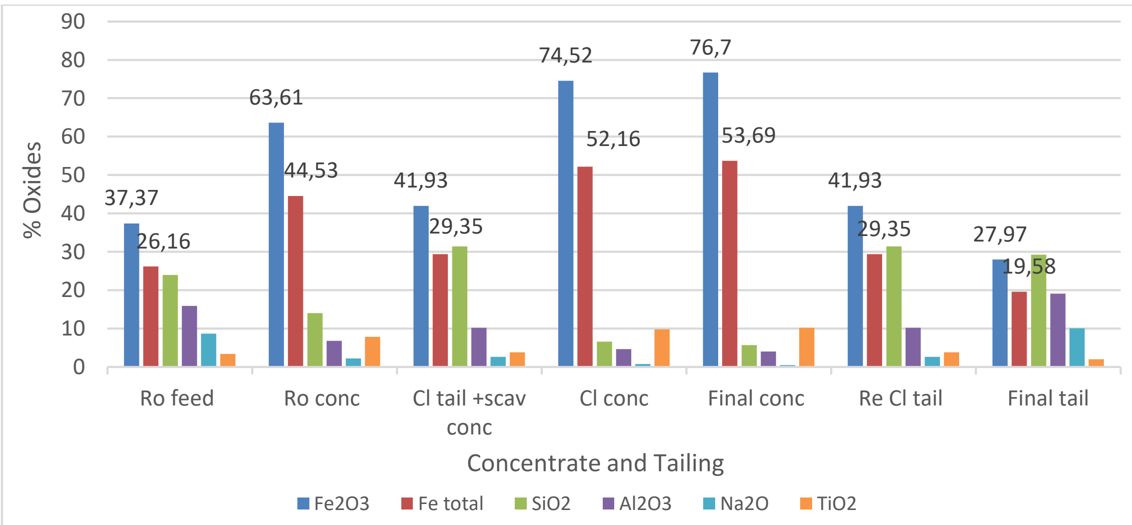


Figure 5. The oxide compound in bauxite residue.



Notes: Ro = rougher; Scav = scavenger; Cl= cleaner; Con= concentrate; Tail=tailings

Figure 6. Composition of selected major oxide resulting from direct magnetic separation process.

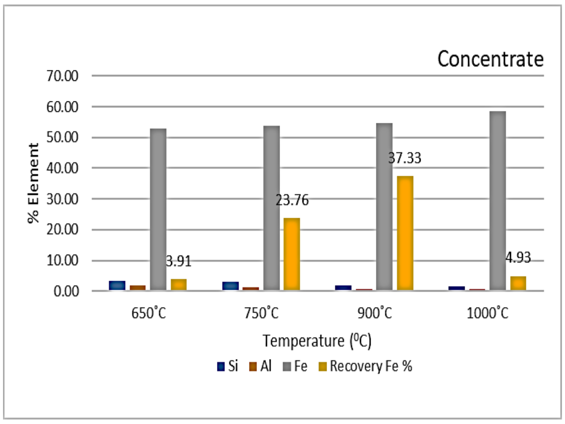
At the rougher stage, the concentrate was obtained with iron oxide content increasing from 37% to 63.61% with total Fe increasing from 26.16% to 44.53% and a recovery of 27.44%, then at the cleaner stage, it became 74.52% with a total Fe of 52.16% with a recovery of 26.72% and at the final stage (re cleaner) obtained the iron oxide to 76.70% with a total Fe of 53.69% and a recovery of 24.54%. Another oxide content in the concentrate that experienced an increase in levels after magnetic separation process was titanium oxide, which successively increased from 3.39% to 7.84% in the rougher, 9.79%

in the cleaner, and 10.21% in the recleaner. On the other hand, for non-ferrous oxides such as silica oxide, alumina oxide, and sodium oxide there was a decrease with the levels in the recleaner (final) being 5.70%, 4.03%, and 0.46%, respectively. Meanwhile, in the tailings product, the iron content produced from the rougher, cleaner, and re-cleaner decreased with the iron content in the recleaner (final stage) being 27.97% with a total Fe of 19.58%. Meanwhile, non-ferrous compounds experienced an increase, except for titanium, which increased as the iron.

This magnetic separation process seems to be still not optimal, because the total Fe value in the final concentrate stage is still relatively low, and the tailings are still relatively high around 53.69% and 19.58%, respectively. The minimum total Fe target that must be achieved in concentrate is 60%. Apart from that, the recovery resulting from multi-stage magnetic separation is still low. The cause is assumed that the iron mineral composition in the raw material is dominated by goethite (34.43%), so it requires a higher magnetic field strength. Li *et al.* (2011) used magnetic separation with a magnetic field strength of 20 kGauss to obtain a total of 65% Fe. A study by Li *et al.* (2014) revealed that the total Fe was always inversely proportional to the recovery percentage obtained being around 58%. It seems that efficient iron separation cannot be conducted using a magnetic separator alone. Another processes/tools needs to be used. Rai *et al.* (2019) succeeded in recovering iron from bauxite residue with a total of 70% Fe and 80% recovery resulting from using a combination of a hydrocyclone and an 18 kGauss magnetic separator. In his study, it was stated that if only a magnetic separator was used, even with a magnetic field strength of 18 kGauss, the total Fe obtained was only 60%. The iron compound phase in the bauxite residue used is hematite. The results of Rai et al.'s study provide a source for future process improvements.

Roasting and Magnetic Separation

The present study involved the roasting of the bauxite residue, followed by magnetic separation in accordance with the flow diagram is depicted in Figure 1. The content of specific elements in the concentrate and tailings of the roasted bauxite residue after magnetic separation process is presented in Figure 7. The roasting process involved temperature variations ranging from 650 to 1000˚C with increments of 100 degrees. This demonstrates that the concentration of iron (Fe) in the concentrate increases somewhat as the temperature increases. The iron content in the tailings varies slightly, with a tendency to increase up to 25%. The bauxite residue that was roasted at a temperature of 750°C had an iron content of 53.73% and a recovery rate of 23.76%. The Fe content increased by 54.57% and the Fe recovery by 37.33% as the roasting temperature was raised to 900˚C. Conversely, elevating the roasting temperature to 1000˚C resulted in a substantial reduction in Fe yield to 4.93% and a significant increase in Fe content by 58.61%.



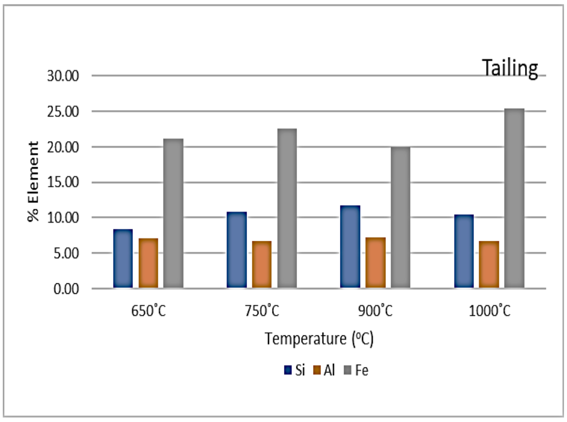


Figure 7. Illustration the impact of roasting and magnetic separation on content of selected elements.

As can be seen in the reaction below, Equation 2, it is assumed that during the roasting process; the free water, chemically bound water, and hydroxyl groups in the goethite structure will be released, causing a phase transformation from goethite to hematite. The goethite content is known to be 34.43%. According to a study conducted by Wang *et al*. in 2020, goethite undergoes a transformation into hematite once the temperature above 600 °C. Hematite has a somewhat higher susceptibility than goethite. Therefore, when subjected to magnetic separation, the magnetic minerals are attracted to the concentrate side. Based on experimental data, it is seen that around 30% of the iron is directed into the concentrate, while the remaining portion is directed towards the tailings. The cause of this may be attributed to the insufficient intensity of the magnetic field employed. Rai *et al.* (2019) employed a magnetic field strength of 18 kGauss to separate hematite minerals from bauxite residue. At a temperature of 1000°C, the recovery rate saw a significant decrease of 4.93%. This decrease is believed to be caused by the recrystallization of the elements Fe, Si, Al, and Na from hematite, gibbsite, and clay, resulting in the formation of new compounds. Further investigation is required to examine the synthesis of compounds by means of XRD examination.

$$2\ FeOOH.\ n\ H_2O \rightarrow Fe_2O_3 + (n+1)\ H_2O \ldots (2)$$

During the roasting process, only transformations between different phases take place. There is no reduction process involved as no reductant is utilised. The Fe content in the roasting process is marginally greater than in the direct magnetic separation procedure. Hence, the absence of a reduction process during roasting appears to be unsuitable for enhancing the separation of the Fe content from other compounds in bauxite residue.

Reduction and Magnetic Separation

This process aimed to transform a substance from no/weak magnetic properties to a high magnetic content reduction process. Goethite (FeOOH) and hematite (Fe_2O_3) are converted to magnetite (Fe_3O_4). This means the reduced product could then be easily separated by magnetic separation. The coal was used as the reductant. The carbon from the coal reacted with the oxygen giving a mixture of gas containing CO and CO_2 as its major constituent. The CO gas provides a reducing atmosphere and helps in hematite reduction (Yu *et al.*, 2022). The reduction reactions are given below eq 3-5 (Liu *et al.*, 2021).

$$2FeO\ (OH) + CO \longrightarrow Fe_2O_3 + CO_2 \ \ldots\ldots\ldots\ (3)$$

$$3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO \ \ldots\ldots\ldots\ldots\ldots\ (4)$$

$$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2 \ \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Figure 8 shows equilibrium systems the transformation of goethite, hematite, and magnetite at different temperatures., it can be seen that the transformation is a step-wise process maintaining to the concentration of CO. Higher CO concentration leads to further reduction of the ore which forms wustite (FeO).

Figure 9 shows the iron content in concentrate obtained from reduction and magnetic separation, using two different fluxes Na_2CO_3 and Na_2SO_4. Both give results with iron content higher than 60% Fe using 2% and 4% of dosage Na_2CO_3 and 4% of Na_2SO_4. When using 8% Na_2SO_4, the iron content tends to decrease. It may cause the formation of wüstite (FeO), which will further affect the magnetic separation result. Comparing the two fluxes used, sodium carbonate is better than sodium sulfate in terms of iron content.

The results shown in Figure 10 indicate that the composition of 8% coal and flux of 4% Na_2SO_4 produces the highest recovery at 87.07% with iron grade/content at 60.74%, while the flux composition of 8% coal + flux of 4% Na_2CO_3 resulted in Fe recovery of 74.73% and concentrate with the highest Fe content of 65.53%. The results obtained are relatively similar to those produced in a study by Zhu *et al.* (2012) that increasing the dose of sodium carbonate increases the effectiveness of removing iron minerals from impurities. The dosage of fluxes is suggested at 4%. Sodium carbonate and sulfate as fluxes each have their advantages, so the choice depends on the desired interest.

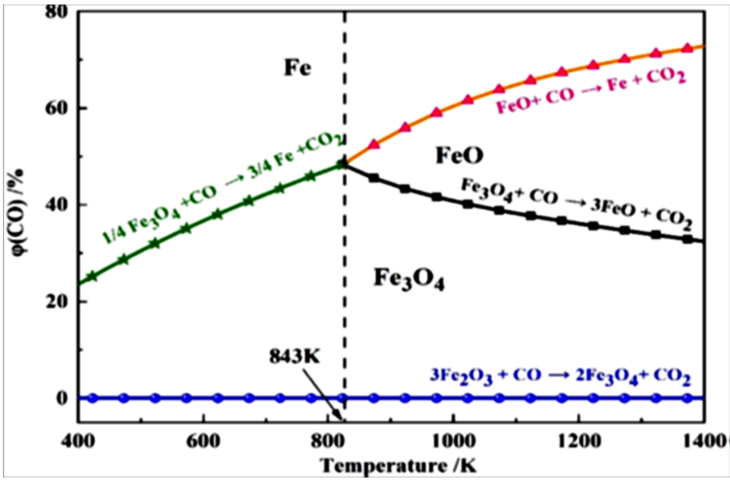


Figure 8. Phase composition of iron mineral for reduction by CO gas (Liu *et al.*, 2020).

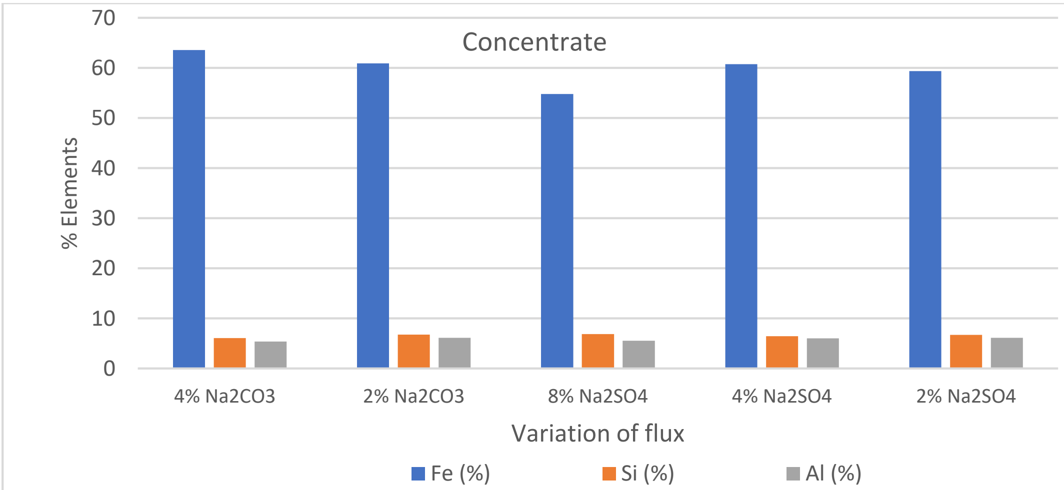


Figure 9. The Effect of fluxes after process reduction-beneficiation of bauxite residue agglomerates.

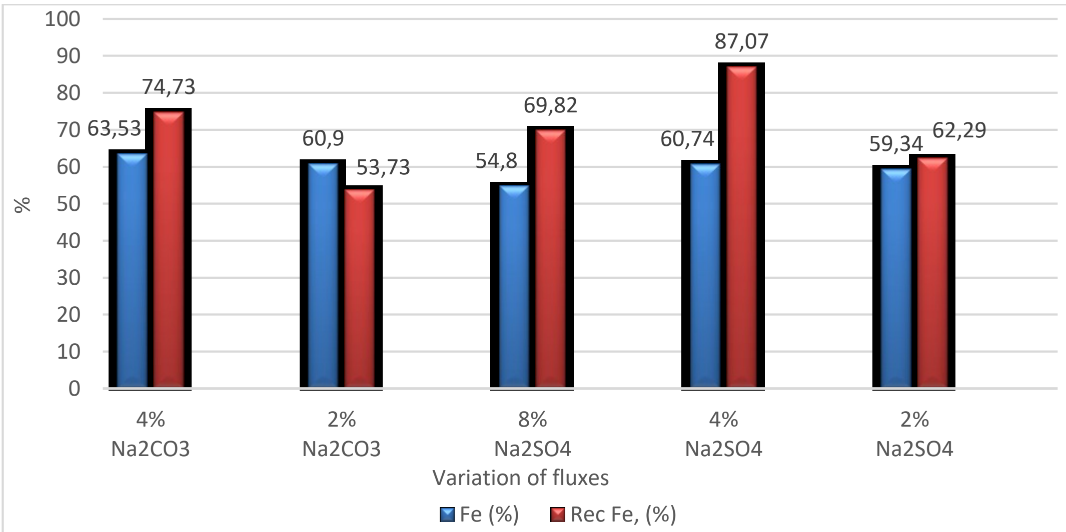


Figure 10. Iron content and recovery with different flux.

CONCLUSIONS

The strategies to utilize bauxite residue have been carried out especially to extract iron minerals contained in bauxite residue. Bauxite residue necessitates being utilized because it contains a valuable metal, the highest content is iron. Iron can be extracted from residual bauxite to produce an iron concentrate. The final iron concentrate, assaying Fe of 60.74% was obtained at an iron recovery of 87.07% under the optimum conditions of Na_2CO_3. Further study is still needed to improve the grade of iron to fulfill as steel raw material.

ACKNOWLEDGMENT

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