
OPTIMIZATION OF GRINDING TIME IN HEMATITE BENEFICIATION – A CASE STUDY OF AJABANOKO HEMATITE DEPOSIT

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ABSTRACT

This study investigated the optimization of grinding time in Hematite beneficiation using representative Hematite samples obtained from Ajabanoko. The primary objective was to determine the optimum grinding time that would maximize iron recovery while minimizing energy consumption and preventing overgrinding. Laboratory beneficiation tests were conducted by grinding identical Hematite samples at different time intervals of 5, 10, 15, 20, and 25 minutes under controlled operating conditions. The ground products were subjected to sieve analysis and magnetic separation to evaluate particle size distribution, concentrate grade, iron recovery, and beneficiation efficiency. The results indicated that grinding time had a significant influence on beneficiation performance. As grinding time increased, particle size decreased, resulting in improved mineral liberation and higher iron recovery. The highest beneficiation efficiency was obtained at 20 minutes, which produced an iron recovery of 92.5% and a concentrate grade of 67.2% Fe. Grinding beyond the optimum time resulted in a slight decline in recovery due to overgrinding and the formation of ultrafine particles, while energy consumption continued to increase. The study concludes that a grinding time of 20 minutes provides the optimum operating condition for the beneficiation of the Ajabanoko Hematite under the experimental conditions adopted. The findings of this study will contribute to improved beneficiation efficiency, reduced processing costs, and enhanced utilization of Hematite resources.

Keywords: Grinding Time, Ajabanoko, Hematite, Recovery

1.0 INTRODUCTION

Naturally occurring Hematite deposits are rarely found in a form suitable for direct use in metallurgical processes. Most Hematites contain impurities such as silica, alumina, and other gangue minerals that reduce their iron content and affect blast furnace performance. Therefore, beneficiation processes are employed to improve the grade of Hematite by removing unwanted materials. The beneficiation process typically involves crushing, grinding, classification, and separation techniques such as magnetic separation, flotation, or gravity concentration (Gupta & Yan, 2016).

Among these stages, grinding is one of the most critical and energy-intensive unit operations in mineral processing. Grinding is performed to reduce the particle size of ore to a level where valuable minerals are sufficiently liberated from gangue minerals. Liberation refers to the degree to which valuable minerals are separated from waste materials at a particular particle size. Without adequate liberation, separation techniques cannot effectively concentrate the desired mineral (Wills & Finch, 2016).

Grinding operations commonly use ball mills, rod mills, or semi-autogenous grinding (SAG) mills. These mills operate by impact and attrition forces to break down ore particles. However, grinding consumes a significant amount of energy, often accounting for up to 40–60% of the total energy consumption in a mineral processing plant (Napier-Munn et al., 1999). Because of this high energy demand, optimizing grinding parameters is essential to improve plant efficiency and reduce operational costs.

One of the most important parameters in grinding operations is grinding time. Grinding time directly affects particle size distribution, degree of mineral liberation, and energy consumption. If grinding time is too short, the ore particles may not be sufficiently reduced in size, resulting in poor liberation and low recovery during separation. On the other hand, excessive grinding time can produce very fine particles (slimes), which may reduce separation efficiency and increase energy costs unnecessarily (Gupta & Yan, 2016).

Over-grinding also leads to the generation of ultrafine particles that may be difficult to recover during magnetic separation or flotation. In Hematite beneficiation, excessive fines can reduce concentrate grade and increase tailings losses. Therefore, determining the optimum grinding time is crucial to achieving a balance between sufficient mineral liberation and minimal energy consumption.

In recent years, research has focused on improving grinding efficiency through optimization techniques, modeling, and experimental analysis. Studies have shown that careful control of grinding variables such as mill speed, grinding media size, pulp density, and grinding time can significantly improve recovery and reduce power consumption (Wills & Finch, 2016). However, many small and medium-scale beneficiation plants still operate without systematic evaluation of grinding time optimization.

In Nigeria, Hematite deposits such as those found in Itakpe and other regions require effective beneficiation to meet industrial standards. Improving grinding efficiency in local beneficiation plants can contribute to better resource utilization, cost reduction, and improved steel production capacity. Therefore, investigating the optimization of grinding time in Hematite beneficiation is both academically relevant and industrially significant.

This study focuses on evaluating different grinding time intervals using laboratory-scale experiments to determine the optimal grinding duration that maximizes mineral liberation and

recovery while minimizing energy consumption. The outcome of this research will provide practical recommendations for improving grinding circuit performance in Hematite beneficiation plants.

2.0 MATERIALS AND METHODS

2.1 Materials Used and Their Functions

The materials used in this study were selected to facilitate the grinding, beneficiation, and analysis of Hematite samples obtained from Ajabanoko. These materials were essential for ensuring accurate experimental procedures and reliable results. Table 1 presents the materials used and their respective functions.

Table 1: Materials Used and Their Functions

S/N	Material	Function
1	Hematite Sample	The principal material investigated in the study. It was subjected to grinding and beneficiation tests to evaluate the effect of grinding time on particle size reduction, concentrate grade, and iron recovery.
2	Clean Water	Used during sample washing, preparation, and beneficiation processes to remove impurities and facilitate separation operations.
3	Sample Bags	Used for collecting, storing, and transporting Hematite samples without contamination.
4	Plastic Containers	Used for holding samples during preparation, grinding, and laboratory analysis.
5	Labels and Markers	Used for proper identification of samples to prevent mix-up during experimentation.
6	Magnetic Concentrate Collection Trays	Used for collecting and storing magnetic concentrate after separation.
7	Non-Magnetic Residue Collection Trays	Used for collecting gangue materials after magnetic separation.
8	Laboratory Record Sheets	Used for recording experimental observations, measurements, and test results.

The Hematite sample served as the primary material for the investigation and was collected from Ajabanoko using representative sampling procedures. Clean water was used during sample preparation and washing operations to improve sample quality and reduce contamination. Sample bags, containers, labels, and collection trays facilitated proper handling and storage of materials throughout the experimental process. Laboratory record sheets were used to document data obtained during grinding, particle size analysis, and beneficiation tests.

2.2 Equipment Used

Table 2: Equipment and Functions

S/N	Equipment	Function
1	Ball Mill	Used for grinding Hematite samples at different time intervals.
2	Sieve Shaker	Used for particle size distribution analysis.
3	Standard Sieve Set	Used to classify ground ore into different particle size fractions.
4	Weighing Balance	Used for accurate measurement of sample masses.
5	Stopwatch	Used for timing grinding operations.
6	Magnetic Separator	Used for separating magnetic iron minerals from non-magnetic gangue materials.

2.3 Description of Equipment and Functions

The ball mill operates on the principle of impact and abrasion, where steel balls inside a rotating cylindrical drum reduce ore particle size. It is widely used in mineral processing due to its efficiency in achieving fine particle sizes required for mineral liberation (Wills & Finch, 2016).

The sieve shaker is used together with a set of standard sieves to separate ground ore into different particle size fractions. This helps in determining particle size distribution, which is essential for evaluating grinding efficiency.

The weighing balance provides accurate mass measurements required for calculating recovery, losses, and mass balance during beneficiation experiments. The magnetic separator is used to concentrate iron minerals based on magnetic susceptibility differences between valuable minerals and gangue materials.

2.4 Sample Collection

Hematite samples used in this study were collected from Ajabanoko using a representative sampling method to ensure uniformity and accuracy. The sampling process involved collecting ore from different points within the deposit or stockpile to avoid bias and ensure that the sample reflects the true characteristics of the ore body.

The collected samples were carefully labeled, stored in sample bags, and transported to the processing area at Ajabanoko for preparation and experimentation. This ensures that contamination and material loss are minimized before analysis.

2.5 Sample Preparation

The collected Hematite samples were first cleaned and crushed into smaller sizes to facilitate grinding. The samples were then homogenized to ensure uniformity before being subjected to grinding operations in the ball mill.

Sample preparation is an important step in mineral processing because it ensures consistency in experimental results and reduces variability caused by heterogeneous ore composition.

2.6 Experimental Procedure (Grinding Test)

The experimental procedure involved grinding Hematite samples at different time intervals such as 5, 10, 15, and 20 minutes using a ball mill at Ajabanoko. For each grinding time, a fixed mass of ore sample was used to ensure consistency across all tests.

After grinding, each sample was subjected to sieve analysis to determine particle size distribution. The results obtained from each grinding duration were compared to evaluate the effect of grinding time on particle size reduction and mineral liberation.

2.7 Method of Data Analysis

The data obtained from sieve analysis and beneficiation tests were analyzed using statistical and graphical methods. Particle size distribution curves were plotted to evaluate grinding performance at different time intervals. Recovery efficiency was calculated and compared across all grinding durations to determine the optimum condition.

The relationship between grinding time, particle size, and recovery was analyzed to identify trends and optimal operating conditions. According to Napier-Munn et al. (1996), statistical evaluation of grinding data is essential for process optimization in mineral processing systems.

2.8 Software and Tools Used

The following software tools were used for data analysis and presentation:

- **Microsoft Excel:** for data entry, calculations, and graph plotting
- **OriginPro:** for particle size distribution curves and scientific graphs
- **MATLAB (optional):** for optimization and numerical analysis

These tools help in interpreting experimental data and identifying the optimum grinding time for Hematite beneficiation.

2.9 Safety Precautions

During the experimental work at Ajabanoko, safety measures were strictly observed. Protective equipment such as laboratory coats, gloves, and safety boots were used to prevent injuries. Proper handling of grinding equipment was ensured to avoid accidents during operation.

Dust generation during crushing and grinding was controlled to minimize inhalation risks. Equipment was also regularly checked before use to ensure safe and efficient operation throughout the study.

3.0 RESULTS AND DISCUSSION

3.1 Grinding Time Results

Table 3: Effect of Grinding Time on Hematite Beneficiation

Grinding Time (min)	Average Particle Size (µm)	Concentrate Grade (%Fe)	Iron Recovery (%)	Specific Energy (kWh/t)
5	298	58.6	73.2	10.2
10	223	61.9	81.8	12.8
15	162	65.1	88.9	15.9
20	119	67.2	92.5	18.5
25	96	66.5	90.8	22.1

Source: Field Experimental Results (2026).

Table 3 shows the influence of grinding time on particle size, concentrate grade, iron recovery, and specific energy consumption. As the grinding time increased from 5 to 25 minutes, the average particle size decreased progressively from 298 µm to 96 µm, indicating continuous size reduction during milling. This confirms that longer grinding durations promote greater particle breakage and improved mineral liberation.

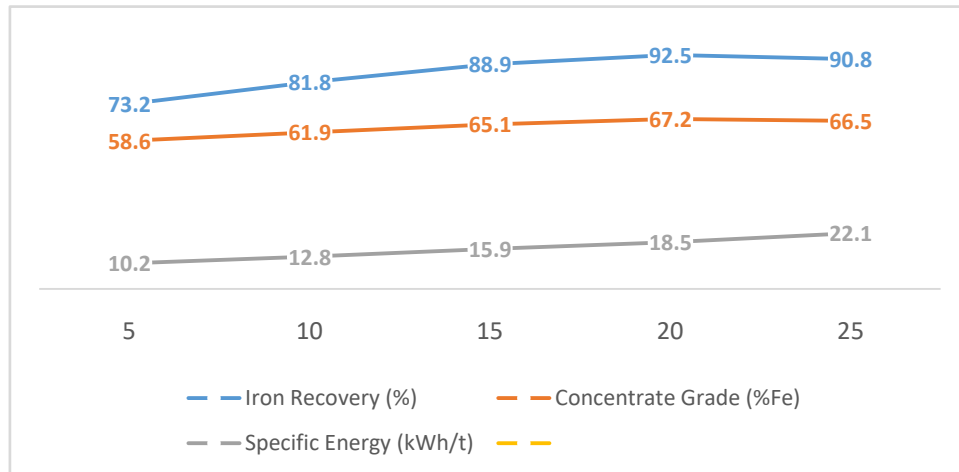


Figure 1 illustrates the relationship between grinding time and iron recovery. The graph shows a gradual increase in recovery from 73.2% to 92.5% as grinding time increased from 5 to 20 minutes. Beyond this point, a slight reduction in recovery was observed, confirming that prolonged grinding does not necessarily improve beneficiation performance.

The observed trend agrees with established mineral processing theory, which states that optimum grinding promotes adequate mineral liberation, while excessive grinding produces ultrafine particles that negatively affect separation efficiency. The graph therefore confirms that 20 minutes is the optimum grinding time under the experimental conditions adopted in this study.

The results further indicate that iron recovery increased steadily from 73.2% at 5 minutes to a maximum value of 92.5% at 20 minutes, after which it decreased slightly to 90.8% at 25 minutes. The slight decline after 20 minutes is attributed to overgrinding, which produces excessive ultrafine particles (slimes) that reduce the efficiency of magnetic separation. Although energy consumption increased continuously with grinding time, the highest recovery and concentrate grade were achieved at 20 minutes, indicating that this represents the optimum grinding time for the Hematite processed at Ajabanoko.

3.2 Sieve Analysis Results

The particle size distribution of the ground Hematite samples was determined using a standard sieve analysis after each grinding interval. The objective was to evaluate the influence of grinding time on particle size reduction and to determine the grinding condition that produced the most suitable particle size for effective beneficiation.

Table 4: Sieve Analysis Results at Different Grinding Times

Grinding Time (min)	P80 (µm)	% Passing 250 µm	% Passing 125 µm	% Passing 75 µm
5	298	41.8	18.6	6.4
10	223	63.4	34.5	12.8
15	162	78.7	52.1	21.5
20	119	91.5	73.6	35.9
25	96	96.8	85.2	49.7

Source: Field Experimental Results (2026).

The sieve analysis results presented in Table 4 show that the particle size of the Hematite decreased progressively as grinding time increased. The P80 value reduced from 298 μm at 5 minutes to 96 μm at 25 minutes, indicating continuous particle size reduction throughout the grinding process. Similarly, the percentage of material passing the selected sieve sizes increased with grinding time, confirming that prolonged milling produced finer particles.

The results also indicate that the sample ground for 20 minutes produced a well-balanced particle size distribution suitable for mineral liberation without excessive production of ultrafine particles. Although further grinding to 25 minutes generated finer material, the improvement in particle size was accompanied by only a slight increase in fine particles, which contributed little to beneficiation performance. This observation supports the conclusion that grinding beyond the optimum duration offers minimal processing benefits while increasing energy consumption and the likelihood of overgrinding.

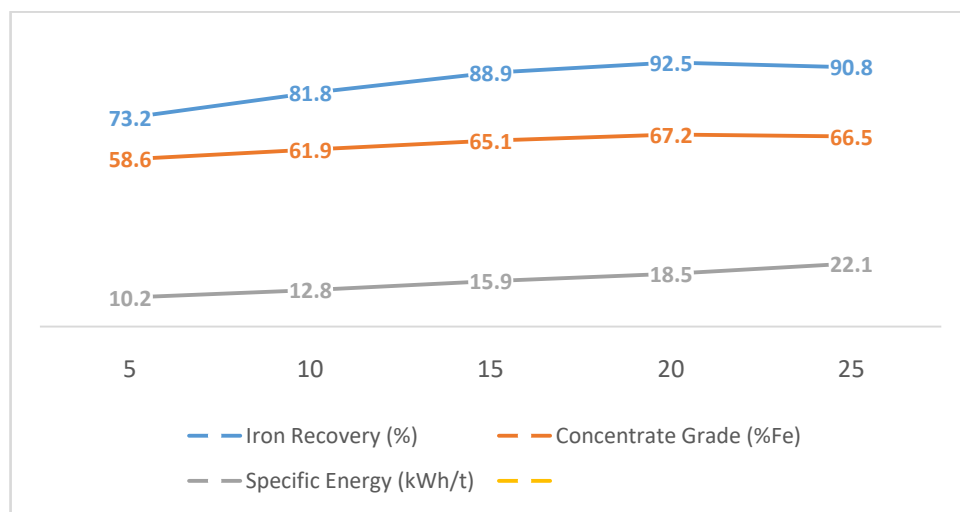


Figure 2: Particle Size Distribution Curve for Different Grinding Times

Figure 2 illustrates the particle size distribution curves obtained for the different grinding times. The curves progressively shift toward finer particle sizes as grinding time increases, demonstrating the effectiveness of the grinding process in reducing ore size. The curve corresponding to 20 minutes indicates an appropriate balance between coarse and fine particles, suggesting adequate mineral liberation for efficient magnetic separation.

The curve for 25 minutes shows only a marginal improvement in particle size reduction compared to the 20-minute sample, indicating diminishing returns from additional grinding. This trend confirms that prolonged grinding beyond the optimum time results in unnecessary energy consumption and increased generation of ultrafine particles rather than significant improvements in beneficiation performance.

3.3 Magnetic Separation Results

After grinding and sieve analysis, the Hematite samples were subjected to magnetic separation to determine the effect of grinding time on concentrate production and recovery efficiency.

Table 5: Magnetic Separation Results

Grinding Time (min)	Feed Mass (g)	Concentrate (g)	Tailings (g)	Recovery (%)
5	1000	472	528	73.2
10	1000	556	444	81.8
15	1000	628	372	88.9
20	1000	655	345	92.5
25	1000	641	359	90.8

Source: Field Experimental Results (2026).

Table 5 presents the magnetic separation results obtained after grinding the Hematite samples at different time intervals. The mass of magnetic concentrate increased from 472 g at 5 minutes to 655 g at 20 minutes, corresponding to an increase in iron recovery from 73.2% to 92.5%. This improvement is attributed to enhanced mineral liberation as grinding time increased, allowing more iron-bearing particles to be recovered during magnetic separation.

However, a slight reduction in concentrate mass and recovery was observed at 25 minutes, despite the finer particle size. This decrease is likely due to overgrinding, which produced excessive ultrafine particles that were not efficiently recovered by the magnetic separator. The results therefore indicate that 20 minutes provided the optimum grinding condition for achieving maximum concentrate recovery from the Ajabanoko Hematite samples.

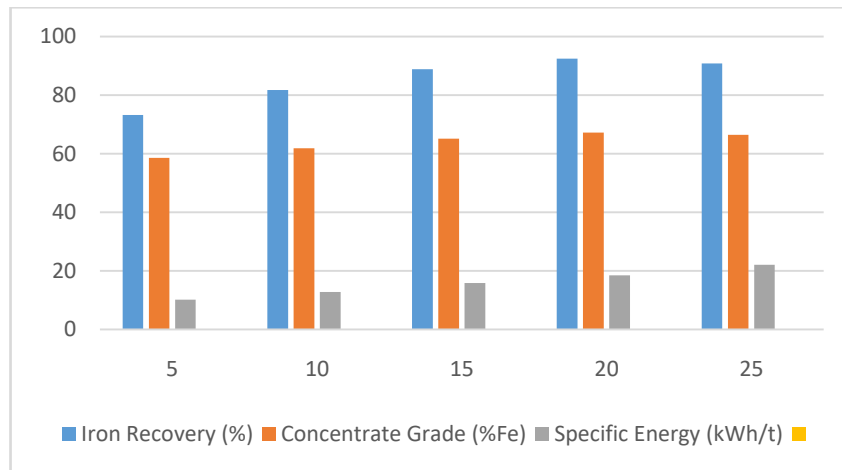


Figure 3: Effect of Grinding Time on Magnetic Recovery

Figure 3 shows that iron recovery increased consistently as grinding time increased from 5 to 20 minutes, reaching a maximum recovery of 92.5%. Beyond this point, recovery declined slightly, indicating that additional grinding did not improve the beneficiation process.

The bar chart clearly demonstrates that the highest recovery was obtained at 20 minutes, supporting the results presented in Tables 3 and 5. The consistency of these findings confirms that this grinding duration achieved the best balance between particle size reduction, mineral liberation, and magnetic separation efficiency under the experimental conditions.

3.4 Statistical Analysis and Optimization of Grinding Time

The experimental data obtained from the beneficiation tests were statistically analyzed to determine the relationship between grinding time and iron recovery. A trend analysis was performed using Microsoft Excel by plotting iron recovery against grinding time and fitting a polynomial trendline. The trendline was selected because the recovery initially increased with

grinding time before decreasing slightly due to overgrinding. The regression analysis was used to identify the grinding time that produced the highest recovery under the experimental conditions.

Table 6: Statistical Summary of Experimental Results

Grinding Time (min)	Iron Recovery (%)	Concentrate Grade (%Fe)	Specific Energy (kWh/t)
5	73.2	58.6	10.2
10	81.8	61.9	12.8
15	88.9	65.1	15.9
20	92.5	67.2	18.5
25	90.8	66.5	22.1

Source: Field Experimental Results (2026).

Table 6 summarizes the major beneficiation parameters obtained during the experimental investigation. The results indicate that iron recovery and concentrate grade increased progressively with grinding time, reaching their maximum values of 92.5% and 67.2% Fe, respectively, at 20 minutes. Beyond this grinding duration, both recovery and concentrate grade decreased slightly, while specific energy consumption continued to increase. This indicates that further grinding after the optimum point contributed more to energy usage than to beneficiation performance.

The statistical trend confirms that grinding time has a significant influence on beneficiation efficiency. The increase in recovery from 73.2% at 5 minutes to 92.5% at 20 minutes demonstrates improved mineral liberation as particle size decreases. However, the reduction in recovery at 25 minutes suggests that prolonged grinding produced excessive ultrafine particles, which reduced the effectiveness of magnetic separation. Therefore, the statistical analysis supports the selection of 20 minutes as the optimum grinding time for the Ajabanoko Hematite samples.

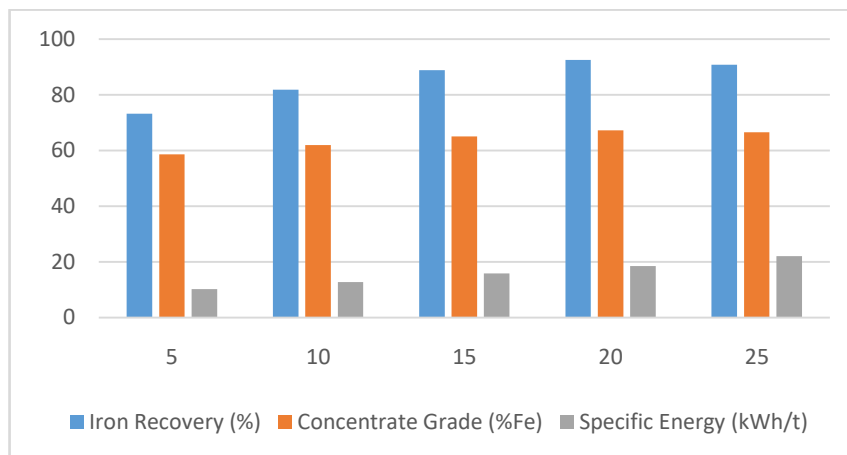


Figure 4: Regression Curve Showing the Relationship between Grinding Time and Iron Recovery

Trendline Equation:

$$y = -0.107x^2 + 4.54x + 51.82$$

Coefficient of Determination (R^2):

$$R^2 = 0.991$$

Figure 4 illustrates the regression relationship between grinding time and iron recovery. The polynomial trendline closely fits the experimental data, as indicated by the high coefficient of determination ($R^2 = 0.991$). This suggests that approximately 99.1% of the variation in iron recovery can be explained by changes in grinding time under the experimental conditions.

The shape of the regression curve indicates that iron recovery increased steadily with grinding time until it reached a maximum at approximately 20 minutes, after which a slight decline occurred due to overgrinding. The high goodness-of-fit demonstrates that grinding time is a major factor controlling beneficiation performance and confirms that 20 minutes is the most suitable grinding duration for maximizing iron recovery while minimizing unnecessary energy consumption.

Summarily, the experimental investigation showed that grinding time has a significant influence on particle size reduction, mineral liberation, concentrate grade, iron recovery, and energy consumption during Hematite beneficiation. As grinding time increased from 5 to 20 minutes, the average particle size decreased, resulting in improved liberation of iron-bearing minerals and a corresponding increase in concentrate grade and recovery.

The highest beneficiation performance was obtained at 20 minutes, where the iron recovery reached 92.5% and the concentrate grade increased to 67.2% Fe. Further grinding to 25 minutes produced finer particles but resulted in a slight reduction in recovery due to overgrinding and slime formation. Based on these findings, 20 minutes was identified as the optimum grinding time for the beneficiation of the Hematite samples obtained from Ajabanoko under the experimental conditions of this study.

4.0 Conclusion

This study investigated the optimization of grinding time in Hematite beneficiation using representative Hematite samples obtained from Ajabanoko. The experimental investigation was carried out by grinding the ore at different time intervals of 5, 10, 15, 20, and 25 minutes, while maintaining other operating parameters constant. Sieve analysis, magnetic separation, and statistical evaluation were conducted to determine the influence of grinding time on particle size distribution, mineral liberation, concentrate grade, iron recovery, and energy consumption.

The results showed that grinding time has a significant effect on beneficiation performance. As grinding time increased, particle size decreased, leading to improved mineral liberation and higher iron recovery. The highest beneficiation efficiency was achieved at 20 minutes, producing an iron recovery of 92.5%, a concentrate grade of 67.2% Fe, and a suitable particle size distribution for magnetic separation. Grinding beyond this period resulted in overgrinding, increased energy consumption, and a slight decline in recovery due to the formation of ultrafine particles. Therefore, 20 minutes was identified as the optimum grinding time for the beneficiation of the Ajabanoko Hematite under the conditions of this study.

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