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Power optimization in mill plant design: Theoretical analysis and AggFlow simulation

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Abstract

Purpose. This study aims to optimize the power consumption of a mill plant by combining theoretical analysis and process simulation using AggFlow software, since power optimization is a crucial factor in enhancing the efficiency and sustainability of industrial milling operations.

Methods. The mill plant, comprising a primary jaw crusher, a secondary double roll crusher, a ball mill, multiple screens, and conveyors, was modeled in AggFlow. A field survey collected specifications of equipment components, and product samples were used for simulation. Theoretical power consumption was calculated and compared with actual field data. Various operational scenarios were simulated to identify opportunities for power consumption reduction.

Findings. The optimized settings, including precise adjustments of gap width, rotational speed and belt speed, resulted in measurable power savings of 17.65% for jaw crusher, 7.69% for roll crushers, 13.33% for ball mill, and 20% for conveyor belts, with a total power consumption reduction of 14.29%.

Originality. This study highlights the effective use of AggFlow software for power optimization in industrial milling processes, providing a new approach to reducing energy consumption in mill plants.

Practical implications. The results provide practical insights for industries aiming to enhance energy efficiency in milling operations. The successful reduction in power consumption demonstrates the potential for integrating process simulation tools like AggFlow into sustainable plant management strategies.

Keywords: *mill plant design, power optimization, energy efficiency, AggFlow simulation, sustainable mining*

1. Introduction

In modern industrial operations, the optimization of power consumption stands as a critical aspect in achieving sustainability, efficiency, and economic viability [1], [2]. Across various sectors, from mining to manufacturing, energy-intensive processes demand careful management and optimization to minimize costs and environmental impact while maximizing productivity [3]-[5]. Central to this endeavor is the design and operation of mill plants, where raw materials undergo processing to yield valuable products.

Mill plants serve as the backbone of numerous industries, including mining, minerals processing, cement production, and chemical manufacturing, among others [6]-[8]. These facilities house a variety of material processing equipment, such as crushers, mills, conveyors, and screens, each consuming substantial amounts of power in their operation. Therefore, the efficient utilization of energy resources at mill plants is of paramount importance for sustaining competitive operations and meeting sustainability objectives [3], [5], [9], [10].

By utilizing AggFlow simulation and optimization capabilities, the proposed mill plant can undergo a thorough analysis and refinement, ensuring that power consumption is controlled, while maximizing operational efficiency and productivity. This comprehensive approach to power optimization not only enhances the sustainability and environmental footprint of the mill plant, but also contributes to its overall economic viability and competitiveness in the industry [6], [11].

In the field of industrial operations, there has been a consistent focus on achieving energy efficiency and sustainability. This has led to extensive investigations into power consumption across different sectors [4], [12], [13]. In the context of mill plants, which involve the processing of raw materials to produce valuable products, it is essential to have a thorough understanding and optimize power requirements in order to ensure economic sustainability and environmental responsibility [9], [10], [13], [14].

There is a substantial amount of literature available on the energy-intensive processes of comminution and crushing, which are essential for mill plant operations. Bond's

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research [15] laid the basis for empirical models that establish a connection between material properties and energy consumption in crushing and grinding operations. Bond's Law, formulated through empirical observations, offers a systematic approach to estimating the energy needed for comminution, taking into account material hardness, size distribution, and various other factors [16], [17].

The paper authored by Liu and Li [18] presents a new crushing index for granular soils, based on the principles of energy consumption theory during crushing, namely the Kick's theory. A reliable index is necessary to quantify particle crushing, which has a significant impact on the properties of granular soils. This study introduces a crushing index, determined by the concept of "size potential" and indicating the energy level of soil particles [18]. The study conducted by Vinogradov et al. [19] focuses on optimizing drilling and blasting methods to achieve the desired particle size distribution and reduce ore dilution in mining activities, specifically in deposits with complex geological structures [19].

Zhang et al. [20] examine the occurrence of coal and gas outbursts and highlight the significance of gas expansion as the main energy provider. They underscore the influence of gas pressure and ground stress on the process of coal fragmentation and transportation [20].

Chimwani [21] examines the difficulties faced by the mineral processing industry, including expensive energy requirements and low-quality ores, through an analysis of crushers and factors that enhance efficiency. The study emphasizes the significance of optimizing downstream processes and reducing energy consumption by improving power management and minimizing idle time in cone and jaw crushers.

Alsafasfeh et al. [22] examine the utilization of Oil Shale Ash (OSA) as an environmentally friendly alternative in cement manufacturing, with a specific emphasis on its impact on power consumption. OSA, which has a high calcium oxide content, is mixed with clinker in different proportions and then examined in the Lafarge factory laboratories. The findings demonstrate that the inclusion of 10% OSA in the clinker enhanced the performance of the product and resulted in a significant 45% decrease in the power consumption of the grinding process, as compared to the reference sample.

Further advancements in comminution research have explored the influence of particle size distribution, feed rate, and equipment design on energy consumption. Studies by Napier-Munn et al. [23] studied the impact of feed size distribution on crushing efficiency and power consumption in jaw crushers and cone crushers. These studies highlight the importance of optimizing feed size distribution to minimize energy consumption while achieving desired product specifications [23], [24].

In the field of grinding and milling, researchers are focused on understanding the energy efficiency of various mill types, such as ball mills, SAG mills, and vertical roller mills. Empirical and semi-empirical models, such as the Bond Work Index have been developed to quantify the energy required for grinding based on material properties and mill operating conditions [16], [17], [24], [25].

Zhou et al. [26] examine the process of producing energy-efficient lignin nanoparticles (LNPs) by grinding high-solid content. The optimal solid loading of 20 wt% was found, resulting in a significant reduction in energy consumption from 30.0 to 3.1 kWh/kg, compared to loading of 1 wt%. Particle concentrations that are higher than 20 wt% impede the efficiency of size reduction because the particles overlap each other. This information can be used to enhance industrial processes.

The work of Fuerstenau & Kapur [10] and Morrel [27] has contributed to our understanding of the factors influencing grinding efficiency and power consumption in ball mills. These studies emphasize the importance of mill geometry, liner design, and feed characteristics in optimizing grinding performance and energy efficiency.

In recent years, computational simulation tools have emerged as valuable assets for optimizing power consumption in mill plants. Software packages such as AggFlow provide powerful platforms for constructing virtual representations of processing plants and conducting detailed energy consumption analyses [6], [11].

However, while considerable research exists on power consumption by individual equipment components, there remains a noticeable gap in the literature concerning comprehensive approaches to power optimization in mill plant design. Few studies have undertaken comprehensive examinations of the collective power requirements of multiple equipment components in mill plants and explored strategies for optimizing energy efficiency throughout the entire processing workflow [27], [28].

This research endeavors to bridge this gap by integrating theoretical analysis with simulation-based optimization techniques, such as AggFlow, to offer a holistic understanding of power consumption by mill plants. Through a synthesis of existing literature and innovative methodologies, this paper seeks to provide insights and recommendations for enhancing energy efficiency and sustainability in mill plant operations.

2. Methodology

2.1. Plant layout and equipment specifications

The performance and efficiency of the existing mill plant rely heavily on the specific configuration and functionality of the installed material processing equipment. Detailed measurements of the equipment were taken on-site to ensure accuracy in specifications. Key parameters such as jaw opening size, roll diameter, ball mill dimensions, and conveyor belt dimensions were documented. Furthermore, operational metrics, including throughput rates, motor power ratings, and rotational speeds, were carefully recorded for each piece of equipment. This data was used for comparison with manufacturer specifications and theoretical power consumption models. Primary crushing is performed by a jaw crusher with a 28.8-inch jaw opening size capable of processing 500 tons per hour. Powered by a 200-horse-power electric motor, the crusher efficiently processes a variety of materials, including hard rocks and abrasive ores, providing a stable feed for downstream operations. For secondary crushing, the plant utilizes a roll crusher with dual rolls measuring 24 inches in diameter and 48 inches in width, operating at 300 rpm. This unit provides flexibility in size reduction with adjustable gap settings, processing 300 tons per hour per roll.

Further down the processing line, a ball mill with a 10-foot diameter and 20-foot length is used for grinding. Operating at 25 rpm, the ball mill is designed to grind material into fine powders, with a capacity of 1000 tons per day. Material is transported between each processing stage using a network of conveyor belts, each 36 inches wide and 100 feet long, equipped with adjustable speed drives and automated controls for precise material handling. Finally, classification and separation are controlled by a multi-layer screens, measuring 6 feet by 12 feet, which have different mesh sizes to ensure effective particle sorting and separation. Together, these components form an integrated system that ensures efficient material flow, from initial crushing to final separation. Table 1 presents an overview of the critical equipment components in the plant.

Besides that, to assess the material flow and efficiency of the crushing and grinding processes, samples were taken from various stages of the processing line. These samples were analyzed to determine particle size distribution and material hardness, providing inputs for the AggFlow simulation software. By comparing pre-crushed feed materials with the results after grinding, it became possible to quantify the efficacy of the crushing and grinding operations.

Real-time data on energy consumption and equipment performance were logged using the plant's automated control systems. Power consumption data for each piece of equipment, including crushers, the ball mill, and conveyors, was recorded. This information allowed for an empirical comparison between the actual power consumption of the plant and theoretical estimates based on standard power consumption models. This data formed the basis for identifying opportunities for energy optimization.

Table 1. Summary of equipment specifications

Equipment	Specifications	Function	Capacity
Jaw crusher	Jaw opening: 28.8 inches, powered by 200 hp motor	Primary crushing	500 tons per hour
Roll crusher	Dual rolls (24 in. diameter, 48 in. width), speed: 300 rpm, adjustable gap settings	Secondary crushing	300 tons per hour per roll
Ball mill	Diameter: 10 feet, length: 20 feet, speed: 25 rpm, uses steel balls for grinding	Pulverizing materials into fine powder	1000 tons per day
Conveyor belts	Width: 36 inches, length: 100 feet, adjustable speed drives, automated control	Material transport between processing stages	Variable, based on material flow
Screens	Dimensions: 6 feet by 12 feet, multi-layer mesh with varying apertures	Particle classification and separation	High throughput screening

2.2. Theoretical analysis of power consumption

In the theoretical analysis of power requirements for material processing equipment in the mill plant, various equations are used to calculate the power consumption of each component. For the jaw crusher, Bond's Law is utilized, relating the work index (W_i) of the material to the power consumption. Equation (1) provides an estimate of the power required based on 80% of the passing feed size (P_{80}) [29], [30]:

$$P = \frac{W_i}{10\sqrt{P_{80}}}, \tag{1}$$

where:

P – power consumption, kW;

W_i – work index of the material, kWh/t;

P_{80} – the 80% passing size of the feed, mm.

Similarly, roll crusher power requirements are estimated using equations that consider factors such as the specific crusher type, material properties, roll surface area, length, feed rate, roll diameter, and rotational speed of rolls [31], [32]. Equation (2) represents one common approach to determining power consumption in roll crushers:

$$P = C1 \cdot A \cdot L \cdot \frac{F}{D \cdot N}, \tag{2}$$

where:

P – power consumption, kW;

$C1$ – coefficient dependent on the specific crusher type and material properties;

A – roll surface area, m^2;

L – roll length, m;

F – feed rate, t/h;

D – roll diameter, m;

N – rotational speed of rolls, rpm.

For the ball mill, power requirements are often estimated using empirical equations or specific energy consumption models. Bond's Law is commonly applied in this context using the Equation (3), which provides an estimate of the power required based on the work index of the material (W_i) and the 80% passing sizes (in µm) of the feed (P_{80}) and product (F_{80}) [30]:

$$P = \frac{10W_i}{\sqrt{P_{80}} - \sqrt{F_{80}}}. \tag{3}$$

In the case of conveyor belts, the power requirement is calculated based on the tension in the belt (T, in N) and the belt speed (V, in m/s) using the Equation (4) [33]. The power requirement can be calculated by knowing the conveyor specifications, such as width, length, weight, inclination and speed, as well as using Equation (5):

$$P = T \cdot \frac{V}{1000 \cdot 3600}; \tag{4}$$

$$HP = Coef.Fraction \cdot \left(\left(\left(2B + W\right) \cdot L\right) \cdot V \cdot SF \cdot 33000\right), \tag{5}$$

where:

B – belt weight per foot;

W – product weight per foot;

L – conveyor length in feet;

H – conveyor incline in feet;

V – conveyor speed;

SF – service factor.

For screens, power requirements are determined by considering factors such as throughput (Q, in t/h), screening efficiency (η), and specific energy consumption (μ, in kWh/t). Equation (6) is commonly used to estimate power consumption in screens:

$$P = Q \cdot \frac{1-\eta}{\eta \cdot \mu}. \tag{6}$$

By using these equations for each component of the material processing equipment, valuable information about the energy consumption of the mill plant can be obtained, which will help optimize its operational efficiency and sustainability.

2.3. AggFlow simulation process

In order to optimize and minimize the power consumption in the existing mill plant, AggFlow simulation software was employed. AggFlow offers a robust platform for developing detailed virtual models of processing plants, which facilitates in-depth analysis and optimization of various parameters, including power consumption [34].

The initial step in utilizing AggFlow involved constructing a comprehensive model of the existing mill plant, incorporating all material processing equipment components described in detail earlier. This included configuring the jaw crusher, roll crushers, ball mill, conveyor belts, and screens within the simulation environment, and specifying their respective capacities, dimensions, and operational parameters.

Once the model was created, various operational scenarios were simulated to assess and optimize power consumption. Key parameters such as feed rates and equipment settings were adjusted to explore their impact on power consumption. The following Table 2 presents the feed rates and settings tested for each equipment component.

Table 2. Simulation parameters for AggFlow

Equipment component	Parameter	Feed rates / settings	Units
Jaw crusher	feed rate	100, 200, 300, 400, 500	tons per hour
	gap width	variable (e.g., 1-5 inches)	inches
	operating speed	variable (e.g., 100-300 rpm)	rpm
Roll crushers	feed rate	100, 200, 300	tons per hour per roll
	roll gap	variable (e.g., 0.5-2 inches)	inches
	rotational speed	variable (e.g., 300-450 rpm)	rpm
Ball mill	feed rate	200, 400, 600, 800, 1000	tons per hour
	rotational speed	variable (e.g., 20-40 rpm)	rpm
Conveyor belts	feed rate	corresponding to above equipment	tons per hour
	speed	variable (e.g., 1-5 m/s)	meters per second
	alignment	variable (e.g., flat, inclined)	–

For instance, jaw crusher feed rates ranging from 100 to 500 tons per hour and gap widths from 1 to 5 inches were tested to observe their influence on crushing efficiency and energy use. Similarly, the roll crusher rotational speeds, varied between 300 and 450 rpm, demonstrated a significant impact on the uniformity of crushed material and power savings. Ball mill simulations with feed rates as high as 1000 tons per hour and rotational speeds ranging from 20 to 40 rpm, have revealed how slower speeds can reduce power consumption while maintaining throughput. Adjustments to conveyor belts, including feed rates linked to upstream equipment and speed variations from 1 to 5 m/s, highlighted their role in reducing unnecessary power consumption during material transportation. These parameters were adjusted to assess their impact on power consumption and identify optimal levels for balancing energy consumption with production efficiency.

3. Results and discussion

3.1. Theoretical analysis of power requirements

The theoretical power consumption was calculated based on equipment specifications, operational parameters, and standard formulas. Actual power consumption data were obtained from control systems and energy meters of the plant. The comparison was conducted for each major component of the processing line: jaw crusher, roll crushers, ball mill, and conveyor belts. The results are presented in Table 3.

Table 3. Theoretical and actual power consumption

Equipment	Theoretical power consumption (kW)	Actual power consumption (kW)	Deviation (%)
Jaw crusher	150	148	-1.3
Roll crushers	100 (per roll)	102 (per roll)	+2.0
Ball mill	300	310	+3.3
Conveyor belts	80	78	-2.5
Total	630	638	+1.3

The comparison of theoretical and actual power consumption, as presented in the Figure 1, revealed generally minor deviations in the equipment, indicating a fairly accurate theoretical model. For example, the actual power consumption of jaw crusher was 148 kW which its slightly lower than the theoretical estimate of 150 kW, resulting in a deviation of -1.3%. This minor discrepancy suggests that the jaw crusher operates slightly more efficiently than anticipated, possibly due to operational conditions or maintenance practices. In the roll mill, the actual power consumption of 102 kW per roll exceeded the theoretical estimate of 100 kW, with a deviation of +2.0%. This increase could be attributed to factors such as material hardness, feed size variations, or wear and tear on the rolls, which may require further investigation.

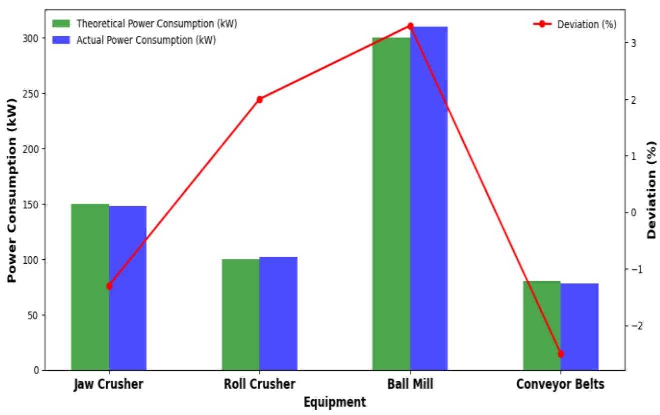

Figure 1. Comparison of theoretical and actual power consumption for key equipment components in the mill plant

The largest deviation was observed in the ball mill with an actual power consumption of 310 kW compared to the theoretical 300 kW. This +3.3% deviation suggests that the ball mill is consuming more power than predicted, potentially due to inefficient grinding or increased material throughput.

To assess the efficiency of power usage in the existing mill plant, the theoretical and actual power consumption values were converted to a per-ton basis. Given a processing rate of 300 tons per hour, this conversion allows for a comparative analysis of power consumption relative to the amount of material processed. As can be seen from Figure 2, the calculations revealed that the theoretical power consumption per ton varied from 0.2 kW/ton for the conveyor belts to 1.00 kW/ton for the ball mill. In comparison, the actual power consumption per ton ranged from 0.26 kW/ton for the conveyor belts to 1.03 kW/ton for the ball mill.

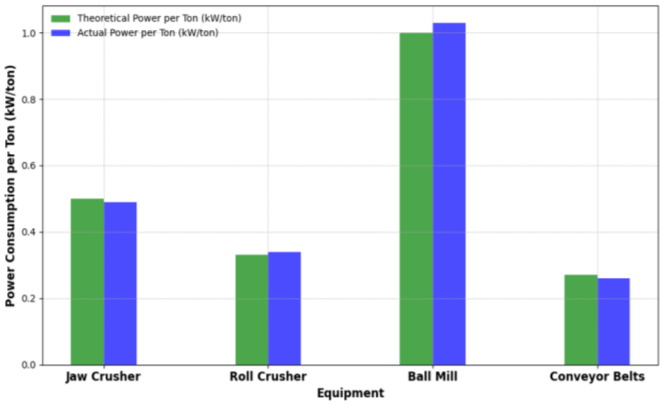

Figure 2. Comparison of theoretical and actual power consumption per ton for various equipment components in the mill plant

The close alignment between theoretical and actual power consumption values was found to be particularly advantageous, as it validated the accuracy of the theoretical models used for predicting power requirements. This agreement ensured that the theoretical values could be reliably employed in AggFlow simulations to test various optimization scenarios. Accurate theoretical predictions were deemed crucial for creating realistic simulations and evaluating the impact of different operational strategies on power consumption. By using these validated theoretical values, effective exploration and implementation of optimization strategies in AggFlow were facilitated, aimed at enhancing energy efficiency while maintaining or improving plant productivity. The accuracy of the theoretical analysis not only validated the models, but also strengthened the basis for informed decision-making in the optimization process.

3.2. AggFlow simulation and mill plant design

The AggFlow simulation process was employed to optimize power consumption in the mill plant without compromising production output. The initial step involved creating a virtual representation of the mill plant using AggFlow. The AggFlow simulation, as depicted in Figure 3, provides a comprehensive representation of the mill plant design and its interconnected components.

This model incorporated all relevant equipment, including the jaw crusher, roll crushers, ball mill, conveyor belts, and screen systems (single and double deck screens).

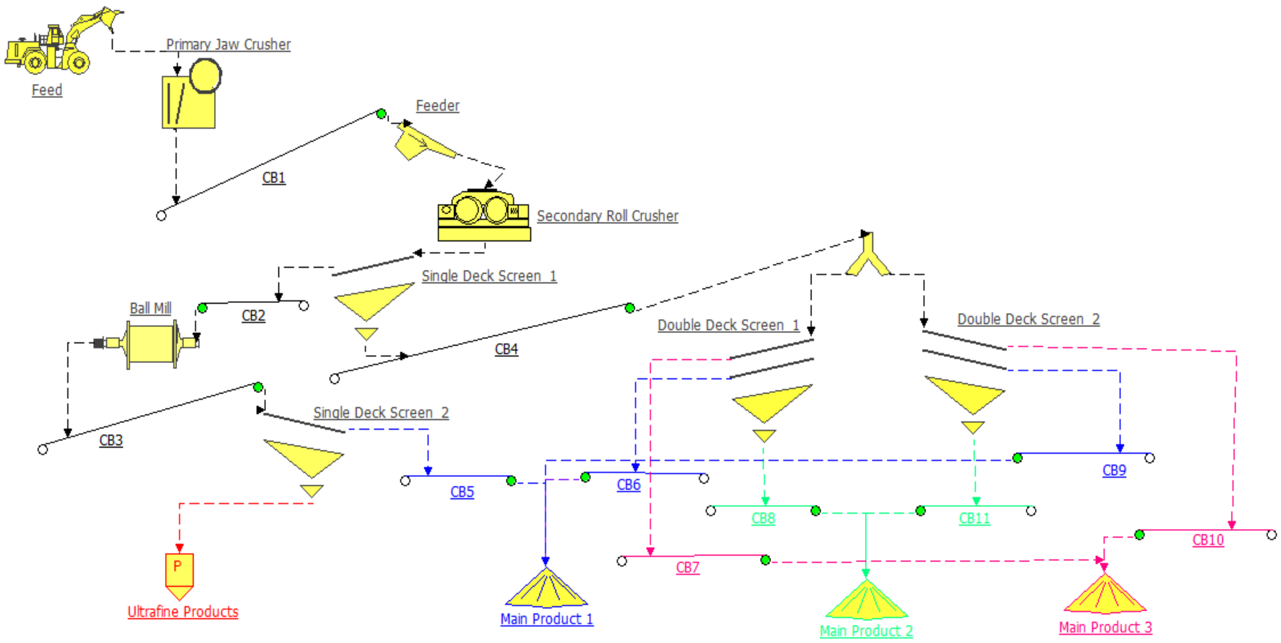

Figure 3. Mill plant design using AggFlow

Each component is integrated into a seamless material processing flow, beginning with feed introduction into the jaw crusher to classifying the main and ultrafine products. The figure highlights the sequential processing stages, emphasizing how material is transferred between equipment via conveyor belts (CB1-CB11). For example, after initial size reduction in the jaw crusher, material is fed to the roll crusher, followed by further classification in single and double deck screens, which direct the materials to the appropriate product streams.

Additionally, the inclusion of multiple product streams (e.g., ultrafine and main products) illustrates the flexibility of the system to handle diverse outputs. This layout helped to estimate the energy consumption of each component while maintaining the desired throughput. By simulating various operational parameters (e.g., feed rates, gap widths, and speeds) in this virtual setup, the study identified bottlenecks and optimized settings to achieve significant power savings.

3.2.1. Effect of feed rates on power consumption

The feed rates were adjusted for the jaw crusher, roll crushers, ball mill, and conveyor belts to determine their effect on overall power consumption and operational efficiency. The simulation results demonstrated how changes in feed rates influence the power consumption of different equipment components. The data were analyzed to identify optimal feed rates that balance energy efficiency with production output. As presented in Figure 4, the power consumption of the jaw crusher increased with higher feed rates. At a feed rate of 100 tons per hour, the power consumption was 50 kW, which rose to 130 kW at a feed rate of 500 tons per hour.

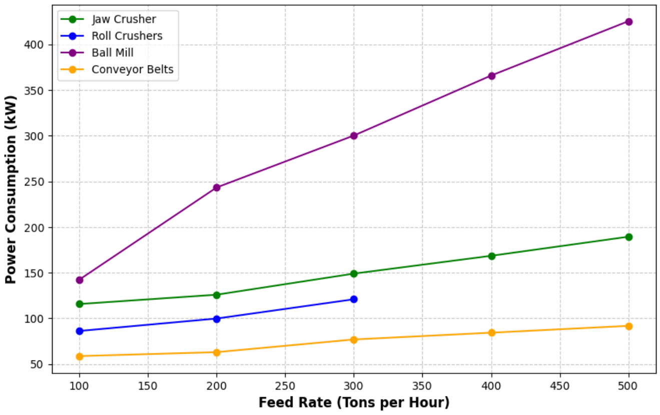

Figure 4. Power consumption in equipment components at different feed rates

This trend indicates that the jaw crusher requires more energy to process larger volumes of material, which is consistent with its role in initial crushing stages. For the roll crushers, the power consumption also increased with feed rate. The power consumption at a feed rate of 100 tons per hour was 40 kW and increased to 70 kW at 300 tons per hour. The moderate rise in power consumption compared to the jaw crusher suggests that while roll crushers also consume more power with higher feed rates, the increase is less pronounced. The ball mill showed a significant increase in power consumption with higher feed rates. At a feed rate of 200 tons per hour, the power consumption was 100 kW, which increased to 180 kW at 1000 tons per hour. The substantial rise in power consumption with feed rate highlights the energy-intensive nature of the grinding process. Power consumption for the conveyor belts increased with feed rates as well, though the rates were lower compared to crushing and grinding equipment. Power consumption rose from 20 kW at 100 tons per hour to 60 kW at 500 tons per hour. This reflects the additional energy required to move larger volumes of material.

3.2.2. Effect of equipment settings on power consumption

The analysis of power consumption across various equipment components was conducted using AggFlow. As presented in Figure 5, the results from the simulations underscore the significant impact of equipment settings on power consumption. For the jaw crusher, wider gap widths and higher operating speeds result in increased power consumption. This pattern is typical for roll crushers, where both roll gap and rotational speed drive up energy requirements. The ball mill shows a marked increase in power consumption with higher rotational speeds, reflecting the increased energy required for grinding. Conveyor belts also demonstrate higher power consumption with increased speeds, aligning with the expectation of higher energy usage for faster material handling. For example, the relationship between the jaw crusher's gap width and its power consumption was analyzed (Fig. 5a). Power consumption increased from 85 kW at a 1-inch gap to 198.7 kW at a 5-inch gap. This trend indicates that larger gap widths require more power, likely due to increased material throughput and processing demands.

For roll crushers, power consumption was examined with varying roll gaps (Fig. 5c). Power consumption increased from 85.8 kW at a 0.5-inch gap to 119.6 kW at a 2-inch gap. This result reflects the higher energy required to process material through wider gaps. The impact of rotational speed on roll crushers was studied (Fig. 5d). Power consumption grew from 84.36 kW at 300 rpm to 120.7 kW at 450 rpm. This increase highlights the additional power needed to drive the rolls faster, which can be attributed to increased friction and operational load.

The primary objective of this study was to identify optimal operating parameters that minimize power consumption without compromising the mill plant's production capacity, which is set at 300 tons per hour. Based on the simulations conducted using AggFlow and the analysis of various equipment settings and feed rates, Table 4 provides a comparative analysis between the field survey data and the optimized settings for key equipment in the mill plant.

The optimized specifications obtained from the simulation reveal significant reductions in power consumption in all components. For instance, reducing the jaw crusher's gap width from 4 to 3 inches and lowering its speed from 250 to 200 rpm resulted in a 17.65% power reduction. Similarly, optimizing the roll crushers and ball mill by decreasing their operating speeds led to power savings of 7.69 and 13.33%, respectively. Conveyor belt speeds were also adjusted, resulting in a 20% power reduction. Overall, the total power consumption decreased by 14.29%, demonstrating that it is possible to significantly reduce energy usage while maintaining production efficiency at optimal levels.

Based on the current study, future research may explore the integration of renewable energy sources, such as solar or wind power, into the mill plant operation to further reduce its environmental footprint. Additionally, the incorporation of advanced machine learning algorithms in AggFlow simulations can provide real-time monitoring and dynamic adjustment of operational parameters, improving both energy efficiency and production consistency.

Further research may also focus on the effects of varying ore compositions and mechanical wear on energy consumption and product quality. Expanding the study to cover more different types of equipment and plant layouts in different sectors of the mining-processing industry will increase the generalizability of the results. Lastly, conducting a cost-benefit analysis of implementing the optimized settings in industrial-scale operations can provide valuable insights into the economic feasibility of these adjustments.

4. Conclusions

This study aimed to optimize power consumption in a milling plant while maintaining consistent production output. Through detailed analysis and the use of AggFlow simulation software, the theoretical analysis is closely aligned with actual power consumption data, confirming the validity of the initial calculations.

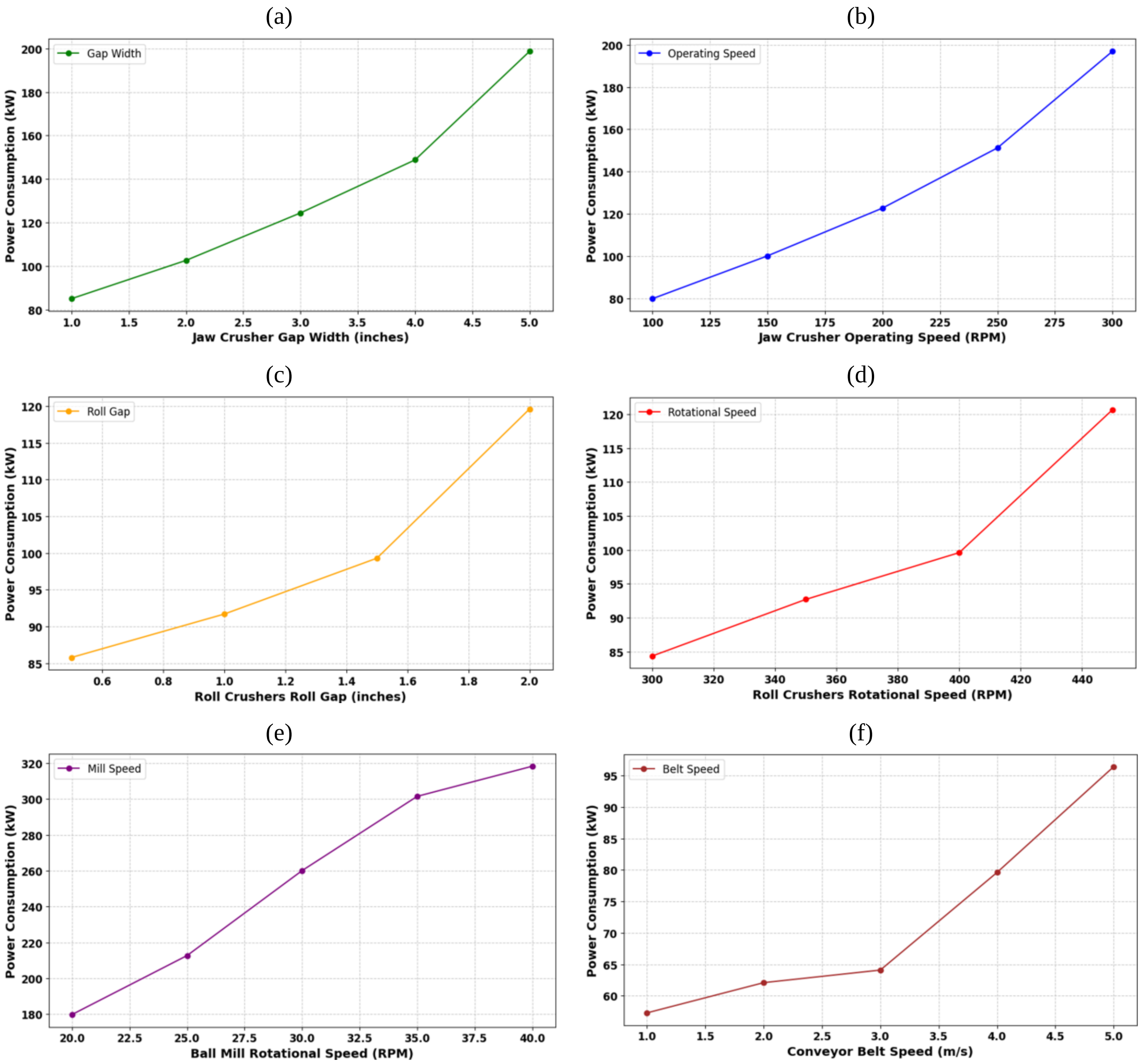

Figure 5. Power consumption of key equipment components in the mill plant: (a) jaw crusher power consumption vs. gap width; (b) jaw crusher power consumption vs. operating speed; (c) roll crushers power consumption vs. roll gap; (d) roll crushers power consumption vs. rotational speed; (e) ball mill power consumption vs. rotational speed; (f) conveyor belt power consumption vs. speed

Table 4. Comparison of equipment specifications and power consumption before and after optimization

Equipment	Specs (field survey)	Power consumption (field survey) (kW)	Specs (optimized)	Power consumption (optimized) (kW)	Reduction (%)
Jaw crusher	Gap width: 4 in; speed: 250 rpm	150	Gap width: 3 in; speed: 200 rpm	123.5	17.65%
Roll crushers	Roll gap: 1.5 in; rotational speed: 400 rpm	100 (per roll)	Roll gap: 1.0 in; rotational speed: 350 rpm	92.31	7.69%
Ball mill	Speed: 35 rpm	300	Speed: 30 rpm	260	13.33%
Conveyor belts	Belt speed: 4 m/s	80	Belt speed: 3 m/s	64	20.00%
Total	–	630	–	~540	14.29%

The simulation enabled a comprehensive assessment of the power demands for various equipment, including jaw crushers, roll crushers, ball mills, and conveyor systems. Adjustments to feed rates, equipment settings, and processing routes proved to have a substantial impact on power consumption.

By optimizing key parameters – such as reducing jaw crusher gap width, lowering rotational speeds in both roll crushers and ball mills, and adjusting conveyor belt speeds – power consumption was reduced in all components without compromising the production capacity. Key results include a 17.65% reduction in power consumption for the jaw crusher by reducing the gap width from 4 to 3 inches and lowering its speed from 250 to 200 rpm. Similarly, power consumption for the roll crushers was reduced by 7.69% by adjusting the roll gap to 1.0 inch and rotational speed to 350 rpm. The ball mill achieved a 13.33% reduction in power usage by decreasing its operating speed from 35 to 30 rpm. Additionally, conveyor belt optimizations, including reducing belt speed from 4 to 3 m/s, resulted in the highest single-component reduction of 20%.

The total power consumption of the mill plant decreased from 630 kW to approximately 540 kW, reflecting a substantial energy savings of 14.29% and demonstrating the potential for energy savings in mineral processing plants.

The study highlights the importance of data-driven optimization in industrial settings. Using simulations to test various scenarios enabled informed decision-making regarding equipment settings and processing routes. This approach not only reduced energy consumption, but also maintained high productivity levels, underscoring the effectiveness of optimization techniques in achieving sustainable operational efficiency in milling processes.

Author contributions

Conceptualization: AAA, AsA; Data curation: AAA, AsA, AmA, RAD; Formal analysis: AsA, AAQ, AEA, AmA, RAD; Funding acquisition: AAA, AAQ, AEA; Investigation: AAA, AsA, RAD; Methodology: AAA, AsA, RAD; Project administration: AAA; Resources: AAA, AsA, AAQ, AEA, AmA, RAD; Software: AsA; Supervision: AAA, AAQ, AEA, RAD; Validation: AAA, AAQ, AEA, RAD, NTA; Visualization: AAA, AsA, AAQ, AEA; Writing – original draft: AAA, AsA, AAQ, AEA, AmA, RAD; Writing – review & editing: AAA, AsA, AAQ, AEA, AmA, RAD, NTA. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Оптимізація потужності при проєктуванні дробильних установок: теоретичний аналіз і моделювання за допомогою програмного забезпечення AggFlow

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Мета. Оптимізація енергоспоживання дробильної установки шляхом поєднання теоретичного аналізу та моделювання процесу подрібнення за допомогою програмного забезпечення AggFlow для подальшого підвищення ефективності й стабільності промислових подрібнювальних операцій.

Методика. Дробильна установка, що складається з первинної щокової дробарки, вторинної дробарки з двома валками, кульової дробарки, декількох грохотів і конвеєрів, була змодельована в AggFlow. Під час польового дослідження були зібрані технічні характеристики компонентів обладнання, а для моделювання були використані зразки продукції. Теоретичне енергоспоживання було розраховано та порівняно з фактичними польовими даними. Були змодельовані різні сценарії роботи, щоб визначити можливості для зниження енергоспоживання.

Результати. Оптимізовано на підставі результатів моделювання технологічні параметри дробильного обладнання: зменшення ширини зазору щокової дробарки з 4 до 3 дюймів та зниження її швидкості з 250 до 200 об/хв; регулювання зазору між валками валкової дробарки до 1 дюйма та швидкості її обертання до 350 об/хв; зменшення швидкості кульового млина з 35 до 30 об/хв. Визначено, що оптимізовані моделюванням налаштування, включаючи точне регулювання ширини зазору, швидкості обертання і швидкості стрічки, призвели до помітної економії електроенергії на 17.65% для щокових дробарок, 7.69% для валкових дробарок, 13.33% для кульової дробарки і 20.0% для конвеєрних стрічок, із загальним зниженням енергоспоживання на 14.29%.

Наукова новизна. Розроблено та доведено можливість використання нового наукового підходу до зниження енергоспоживання на дробильних установках із використання програмного забезпечення AggFlow.

Практична значимість. Результати дослідження надають практичну інформацію для галузей промисловості, які прагнуть підвищити енергоефективність під час подрібнювальних операцій. Успішне зниження енергоспоживання демонструє потенціал інтеграції інструментів моделювання процесів, таких як AggFlow, у стратегії сталого управління установкою.

Ключові слова: *проєктування дробильних установок, оптимізація енергоспоживання, енергоефективність, моделювання у програмі AggFlow, сталий розвиток гірничодобувної галузі*

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