# Campaign Processing of Ores from Santa Elena and Ermitaño Mines using the same Comminution Circuit

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## Abstract

The Santa Elena Silver/Gold Mine in Mexico is 100% owned by First Majestic Silver Corp.; it comprises mining concessions that total 102,244 hectares. The Santa Elena mine operation consists of the Santa Elena underground mine and the Ermitaño underground mine. The Santa Elena processing plant is currently using a campaign method of ore processing to treat the Santa Elena and Ermitaño ores separately, due to the ores' distinct hardness and liberation characteristics. To achieve optimum levels of metal recovery and the corresponding maximum metal production, the operating throughput is targeted at 3,200 tonnes per day (t/d) for Santa Elena and 2,500 t/d for Ermitaño. Part of the grinding circuit is the 1600 kW vertical stirred mill from Swiss Tower Mills Minerals, commissioned in July 2019; it provides the required large range of operational flexibility to handle large varying operating conditions. This paper discusses the unique approach to operating with one processing plant for two significantly different ores.

## Keywords

Campaign processing, vertical stirred milling, operational flexibility, fluctuating process conditions, process plant optimization, process control, energy efficiency

## Introduction

At the First Majestic Silver Corporation-owned Santa Elena Silver / Gold processing plant, ores from the Santa Elena and Ermitaño underground mines are processed in a campaign style using a single processing plant. However, due to distinct ore characteristics, the operating throughput targets differ, with 3,200 tonnes per day (t/d) for the Santa Elena campaign and 2,500 t/d for the Ermitaño campaign. Essential in the flowsheet is the 1600 kW vertical stirred mill from Swiss Tower Mills Minerals (STM Minerals), which provides a wide range of operational flexibility. This paper discusses the innovative approach of using a single processing plant for two significantly different ores, highlighting the operation's process flexibility and ability to maximize metal production.

## Santa Elana Process Overview

Santa Elena has undergone two phases of plant expansion; its current process flowsheet is shown in Figure 1. The flowsheet consists of a three-stage crushing circuit, primary wet ball mill equipped with variable-speed drive (VSD), secondary vertical stirred mill, cyanide leaching, counter current decantation (CCD) thickeners, and tailings filter press. The ores from underground mines are processed into gold–silver doré bar through a Merrill-Crowe process. The tailings generated by the processing plant are filtered and deposited as dry-stack tailings.

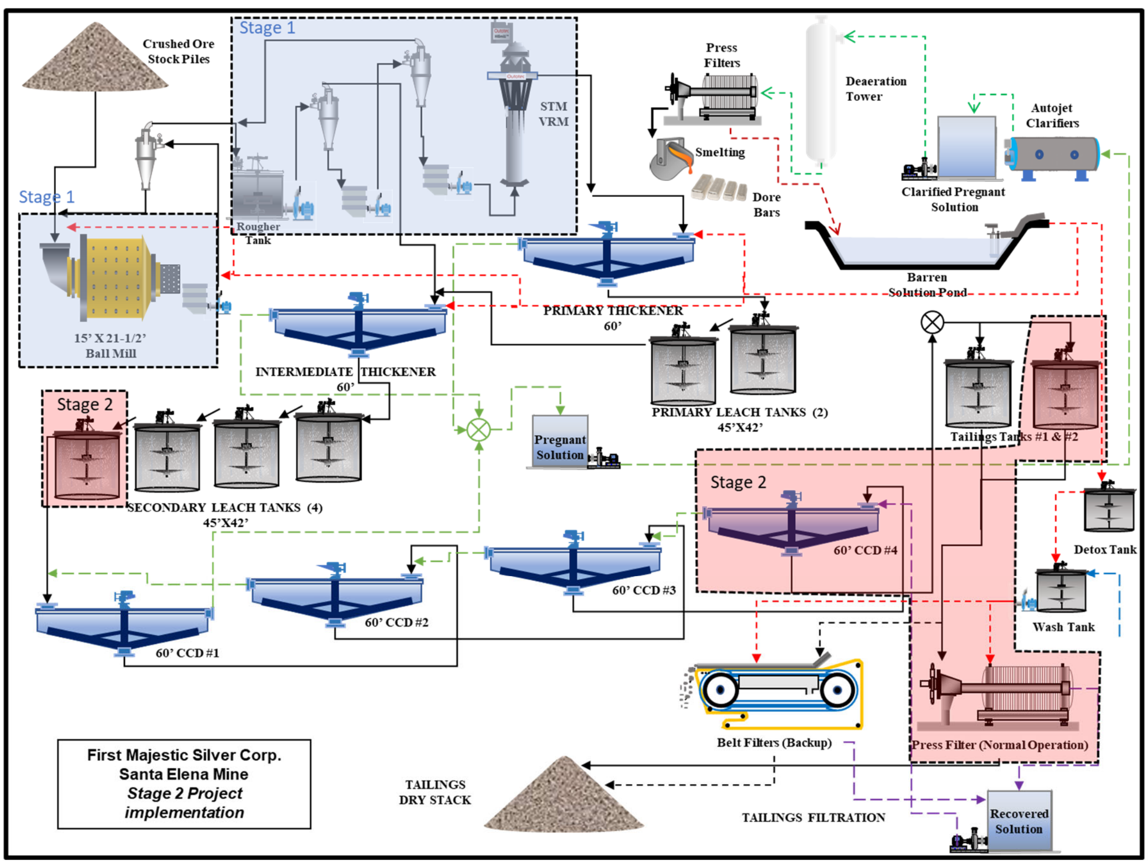


Figure 1—Santa Elena Process Flowsheet

## Ore Characteristics and Process Requirements

Extensive comminution tests, including Bond rod mill work index (RWi), Bond ball mill work index (BWi), and fine grinding signature plot, have been conducted on both the Santa Elena and Ermitaño ores. Figure 2 to Figure 4 provide direct comparisons of the ore hardness characteristics for the two ores, highlighting that the Ermitaño ores exhibit significantly higher ore hardness compared to Santa Elena ores. These differences in ore-hardness characteristics would directly impact the throughput capacity and achievable grind size for a given processing plant.

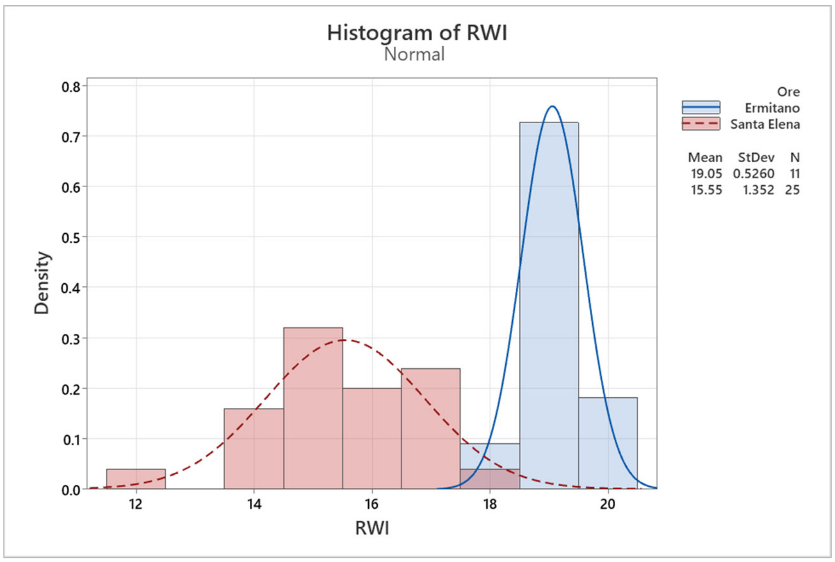


Figure 2—Rod Mill Work Index Results for Santa Elena and Ermitaño Ores

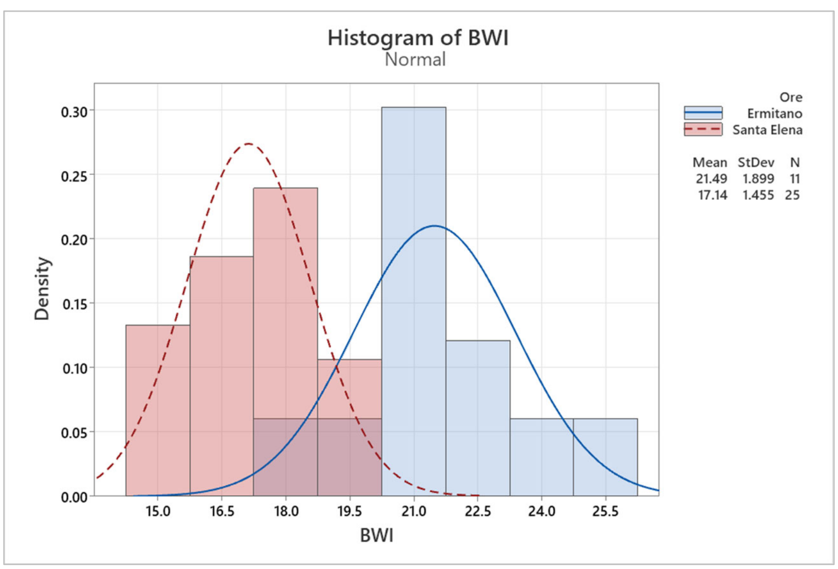


Figure 3—Ball Mill Work Index Results for Santa Elena and Ermitaño Ores

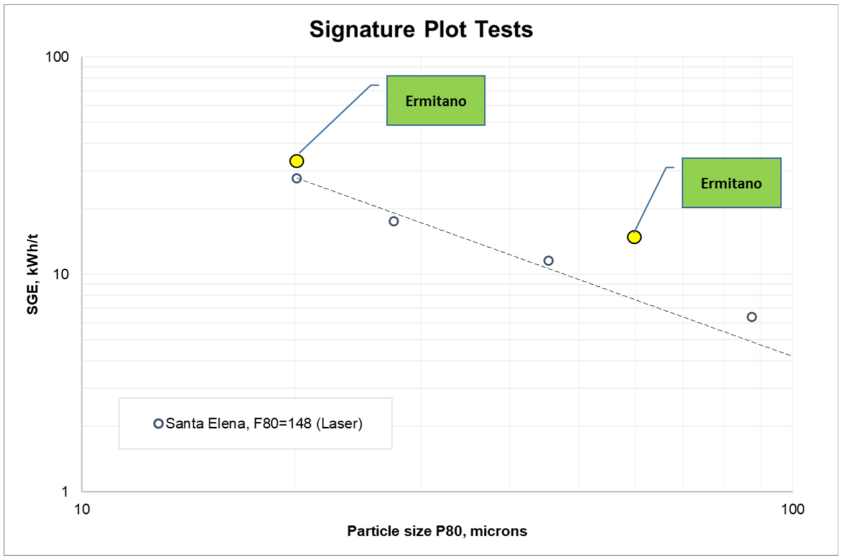


Figure 4—Fine Grinding Signature Plot for Santa Elena and Ermitaño Ores

In addition, mineralogy and leaching testwork conducted on the Ermitaño ores have revealed that the gold and silver are present in much finely disseminated forms compared to ores from Santa Elena mine. As a result, Ermitaño ores are more sensitive to grind size concerning leaching kinetics and metal recovery. To achieve acceptable metal recoveries, the Ermitaño ores would require a finer grind size in the extraction process. As a result, when using the same processing plant at Santa Elena, a lower throughput rate must be targeted for Ermitaño ores. Additionally, the varying operating conditions of the two different ores present a unique challenge, highlighting the need for the process flowsheet to be robust and flexible to handle large variations in operating conditions.

## Process Design Criteria

Table 1 summarizes the general process design criteria for the comminution circuit processing Santa Elena and Ermitaño ores, respectively.

Table 1—General Process Design Criteria

| Description | Unit | Santa Elena | Ermitaño | Basis/Comment |
|---|---|---|---|---|
| ***Ore Hardness*** | | | | |
| Drop Weight Axb | - | 45 | 43 | $P_{75}$ |
| Rod Mill Work Index (RWi) | kWh/t | 16.7 | 19.3 | $P_{75}$ |
| Ball Mill Work Index (BWi) | kWh/t | 18.2 | 22.7 | $P_{75}$ |
| Fine Grind Specific Grinding Energy | kWh/t | 9.0 | 14.0 | $P_{80}$ 50 µm |
| ***Production*** | | | | |
| Throughput Rate | t/d | 3,200 | 2,500 | |
| Throughput Rate | t/h | 133 | 104 | 24 hours |
| Grind Size $P_{80}$ | µm | 50 | 50 | |

Note: kWh/t = kilowatt hours per tonne; µm = microns; t/h = tonnes per hour; $P_{75}$ = 75% passing; $P_{80}$ = 80% passing.

## STM Vertical Stirred Mill

Over a decade ago, STM Minerals introduced a vertical stirred mill known as the Vertical Regrind Mill (VRM), after obtaining the license from a privately owned company in the industrial minerals industry with numerous operations around the globe.

### GRINDING MECHANISM

The VRM consists of a suspended mill chamber oriented vertically, with grinding rotors (discs with castellations) installed on a rotating mill shaft. The mill operates with a slurry feed with a solid density ranging typically between 40% and 55% by weight. The feed entry is at the bottom of the mill, while the discharge is located at the opposite side at the top. The mill chamber is typically filled to around 60% of its volume with ceramic grinding media, as shown in Figure 5.

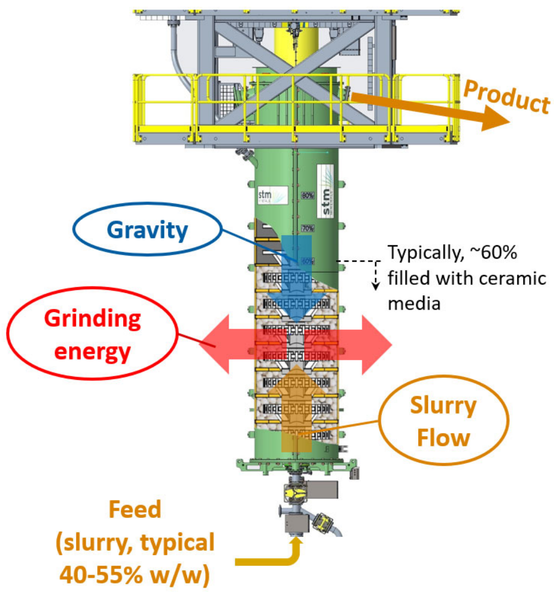


Figure 5—Typical STM Vertical Mill Cross Section

The grinding media bed moves in a circular motion only in the horizontal plane, with no random lifting or dropping of the media bed. The actual grinding process is driven by attrition between the grinding media and the feed particles. The optimal contact required between the grinding media and the feed particles is achieved by the bottom feeding-system combined with the vertical mill orientation. Moreover, this configuration offers a notable advantage that prevents coarse particles from short-circuiting within the mill, as there is no direct path available for this to happen.

The mill shell is internally equipped with 360° stator rings which sit between two grinding rotors, creating a set of consecutive grinding chambers. Similar to a hydrocyclone, centrifugal force pushes the coarser and denser particles, together with the dense ceramic media, to the periphery of the chambers, into the high intensity grinding zones. Meanwhile, finer particles travel upwards towards the centre of the mill, largely avoiding any further grinding action. As shown in Figure 6, the selective grinding mechanism results in energy-efficient size reduction, as the energy from the mill motor is primarily applied to the coarser particles.

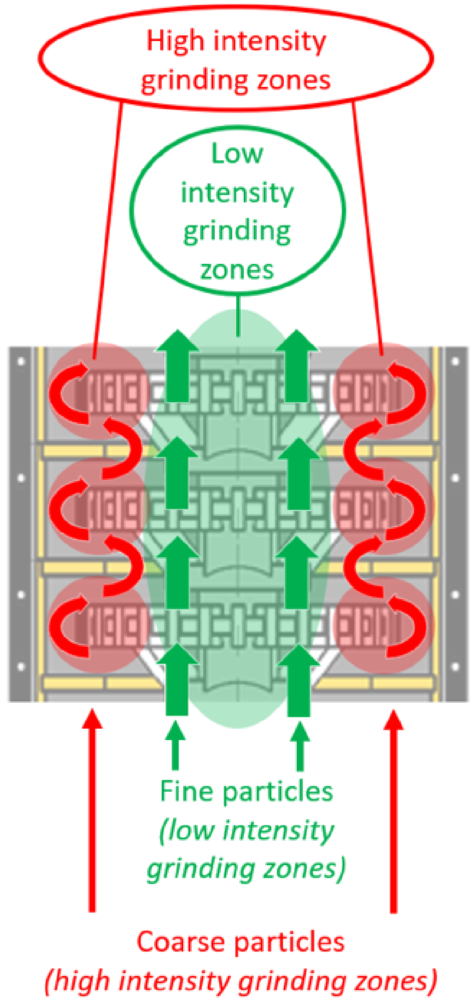


Figure 6—Selective Grinding in the STM Vertical Mill

The main mill motor that drives the mill shaft and grinding rotors is always equipped with a VSD. Mill speed variation directly affects the mill's power draw in an instantaneous fashion, enabling adjustment on the actual specific grinding energy (SGE) and control of the mill discharge $P_{80}$. The open-circuit configuration is only possible due to the mill's unique features, which includes a selective grinding mechanism, variable mill speed, and avoidance of a possible short-circuit path for coarse particles. A scalping device, typically hydrocyclones, can be installed in front of the mill to enhance the milling operation.

Mezquita et al. (2022) demonstrated the energy-efficiency benefit of the VRM over a conventional ball mill. As shown in Figure 1 and Figure 7, a two-stage classification system was used to scalp the ball mill cyclone overflow, with the coarse fraction (underflow of the second scalping cyclone) reporting to the VRM. Prior to installing the VRM, the ball mill was operating at the maximum power draw of 2200 kilowatts (kW) and achieving a product with 80% passing ($P_{80}$) around 75 µm. While the VRM was being installed, the ball mill was undergoing an upgrade from fixed speed to variable speed that allows instantaneous adjustment on the ball mill energy input. Figure 8 shows that the installation of the VRM resulted in a finer product size with a lower combined power draw in the ball mill and VRM, while processing ore with similar hardness characteristics.

Figure 7—Ball Mill, Two-Stage Classification and VRM

Table 2—Santa Elena Comminution Equipment Specification

| Description | Unit | Value |
|---|---|---|
| ***Ball Mill*** | | |
| Mill Dimension | ft x ft | 15 x 21.5 |
| Motor Power | kW | 2,200 |
| Primary Cyclone | - | 5 x gMax 15 |
| ***Two-Stage Classification*** | | |
| Rougher Cyclone | - | 12 x gMax 6 |
| Cleaner Cyclone | - | 8 x gMax 6 |
| ***VRM*** | | |
| Motor Power | kW | 1600 |
| Mill Volume | L | 9,000 |
| Shaft Speed, Nominal (Min–Max) | rpm | 158 (107–189) |
| Tip Speed, Nominal (Min–Max) | m/s | 9.6 (6.5–11.5) |

Notes: ft = feet; L = litres; kW = kilowatts; m/s = metres per second; rpm = revolutions per minute.

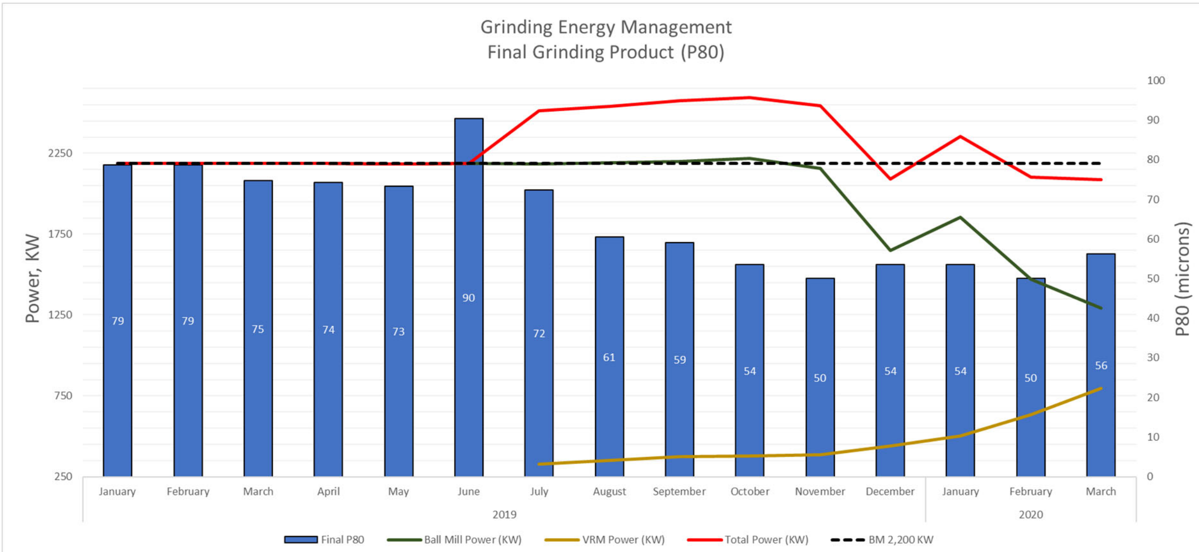


Figure 8—Efficiency Gain of the VRM Over a Ball Mill (Mezquita et al., 2022)

## OPERATIONAL FLEXIBILITY

The Vertical Regrind Mill (VRM) technology provides several levels of flexibility, such as:

- By varying the mill speed, the actual mill power draw (energy input) can be instantaneously adjusted.
- By varying the grinding media filling level, the actual mill power draw can be adjusted.
- By changing the mill internal component specifications, the actual mill power draw can be decreased, i.e., increasing the spacing between the grinding rotors (and the stator rings) or by installing grinding rotors with a smaller diameter.

If the mill power draw can be adjusted in such a controlled manner, then the opportunity arises to better regulate the actual mill discharge $P_{80}$ value. This helps prevent over-grinding, especially when the mill feed size is finer, or the mill feed is softer, or the mill feed rate is lower (which is common during the ramp-up phase). During the commissioning of the 1600 kW VRM at Santa Elena in the summer of 2019, the mill required a low power draw of approximately 300 kW for the initial months. As shown in Figure 9, this was achieved effortlessly.

The enormous operational flexibility the VRM offers also provides the opportunity to process different ores with completely different characteristics, hardness, and target product sizes.

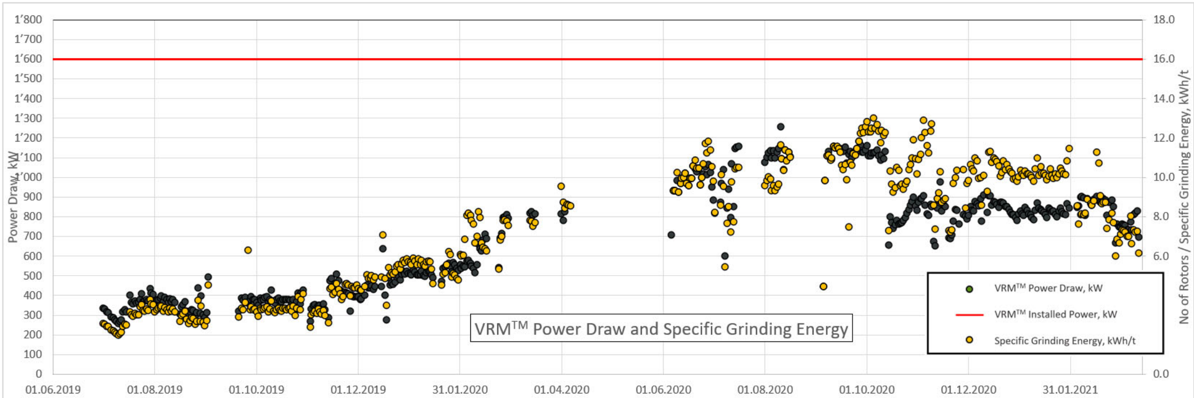


Figure 9—Large Power Turn-Down Ratio of the 1600 kW VRM at Santa Elena During Ramp-Up

## Results from the Different Operating Process Campaigns

Table 3 provides an overview of the VRM operating parameters from January 2022 to April 2023, with separate statistics for the Santa Elena and Ermitaño campaigns. The primary differences between these campaigns lie in ore hardness and grind size; therefore, the processing plant has been adjusted accordingly for each campaign to handle varying feed throughput-rate, transfer size, and SGE requirement. One of the ongoing optimization efforts is to increase VRM power draw (using mill speed and media specific gravity) during the Ermitaño campaign to achieve a more favorable grind size and improved downstream metal recovery.

Table 3—VRM Operating Parameters (January 2022—April 2023)

| Variable | Unit | Santa Elena—SE (2022) | Ermitaño—ERM (2022–2023) | Ermitaño—ERM 2023 |
|---|---|---|---|---|
| ***Plant Throughput*** | | | | |
| Mean | t/h | 115 | 98.9 | 96.8 |
| StDev | | 19.5 | 7.9 | 9.0 |
| ***Mill Feed Flow*** | | | | |
| Mean | $m^3/h$ | 117 | 106 | 99 |
| StDev | | 11 | 9 | 5 |
| ***Mill Feed Solid*** | | | | |
| Mean | % | 48 | 49 | 50 |
| StDev | | 4 | 4 | 2 |
| ***Mill Tip Speed*** | | | | |
| Mean | m/s | 10 | 10 | 10.5 |
| StDev | | 1.2 | 1.1 | 0.9 |

| Variable | Unit | Santa Elena—SE (2022) | Ermitaño—ERM (2022–2023) | Ermitaño—ERM 2023 |
|---|---|---|---|---|
| ***Mill Power*** | | | | |
| Mean | kW | 1084 | 1155 | 1343 |
| StDev | | 150 | 162 | 198 |
| ***Mill SGE*** | | | | |
| Mean | kWh/t | 8.3 | 11.3 | 13.4 |
| StDev | | 2.8 | 2.2 | 2.0 |
| ***Mill $P_{80}$*** | | | | |
| Mean | µm | 48 | 60 | 54 |
| StDev | | 14 | 24 | 23 |

Notes: $m^3/h$ = cubic metres per hour; m/s = metres per second; StDev = standard deviation.

Figure 10 shows the relationship between applied SGE and the resulting product fineness for both Santa Elena and Ermitaño ores, based on data collected from January 2022 to April 2023. The SGE reported in the plant aligns reasonably well with the signature plot tests conducted in the laboratory with a VRM test mill. Moreover, the data confirms the difference in ore hardness between Santa Elena and Ermitaño ores, with the latter requiring a higher SGE for the same product size target.

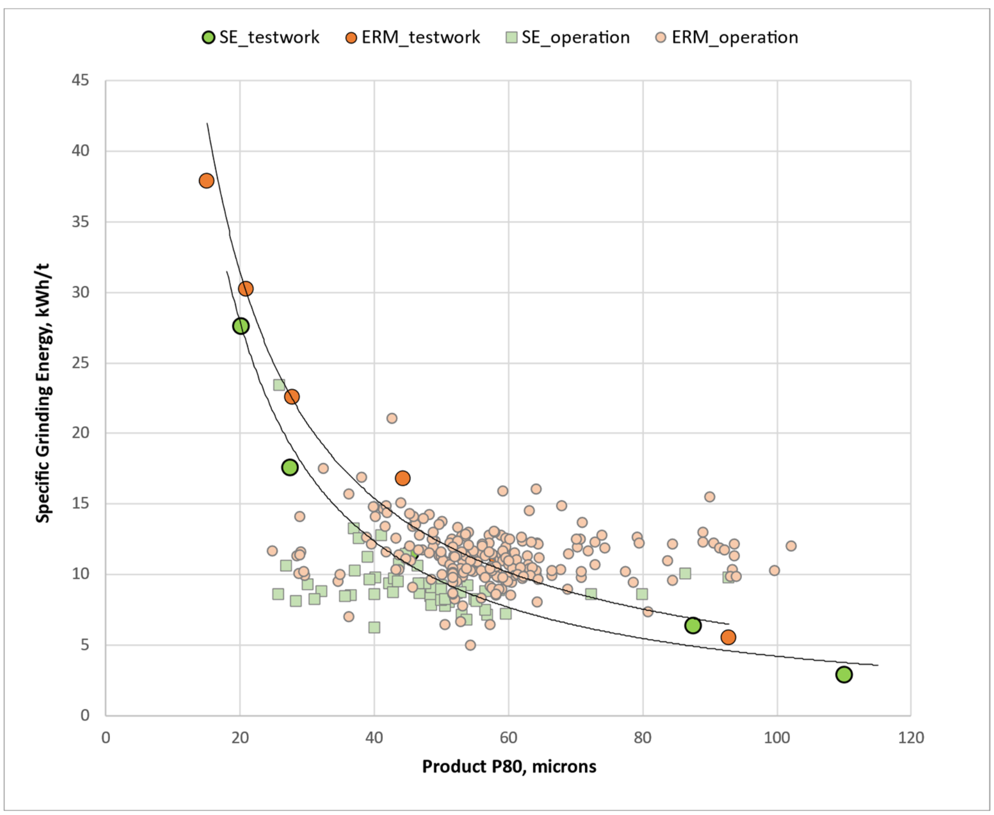


Figure 10—Operating Process Data vs. Signature Plots

To improve the understanding of the VRM operation, the site team conducted a multi-variable analysis using operational data obtained during the Ermitaño campaign. This analysis was instrumental in developing practical mill power draw model and SGE model. This analysis took into account several key operational parameters, such as the feed solid content (% by weight), media filling level (%), mill speed (m/s), and feed flow rate ($m^3$/h). The results of the analysis are presented in Table 4, revealing adjusted R-Square values of 0.64 for mill power draw and 0.79 for SGE. While there remains room for enhancing the model accuracy as the operational database expands, the existing model already proves to be valuable in providing essential guidance to the operation. It highlights the most influential parameters that should be adjusted to enhance process performance. As the operational database grows and the model continues to evolve, the potential for further improvement becomes apparent.

Table 4—Operational Models for Mill Power and SGE

| **Predictor Variable** | **Mill Power (kW)** | **SGE (kWh/t)** |
|---|---|---|
| X1—Feed Solid Content, wt.% | 7.82 | −0.192 |
| X2—Media Filling Level, vol% | 2.99 | 0.0392 |
| X3—Mill Speed, rpm | 56.9 | 0.695 |
| X4—Flow Rate, $m^3$/hr | −17.63 | −0.3643 |
| Intercept | 1957 | 55.13 |
| R Square | 0.67 | 0.81 |
| Adjusted R Square | 0.64 | 0.79 |
| Standard Error | 124 | 1.55 |

Figure 11 and Figure 12 compare the predicted power draw and SGE to those measured from the operation. The developed models can be useful in guiding operation, and there are plans to use these models to develop predicted controllers that can potentially improve the existing process control capability. As evident from the graphs, there were a few data points that stood out as clear outliers. One possible explanation for these anomalies could be the accuracy of the online instruments used, such as the densometer and flowmeter. This observation underscores the criticality of regular calibration of these instruments to ensure their proper functioning and accuracy in data collection. Frequent calibration is essential to maintain the reliability and precision of prediction models.

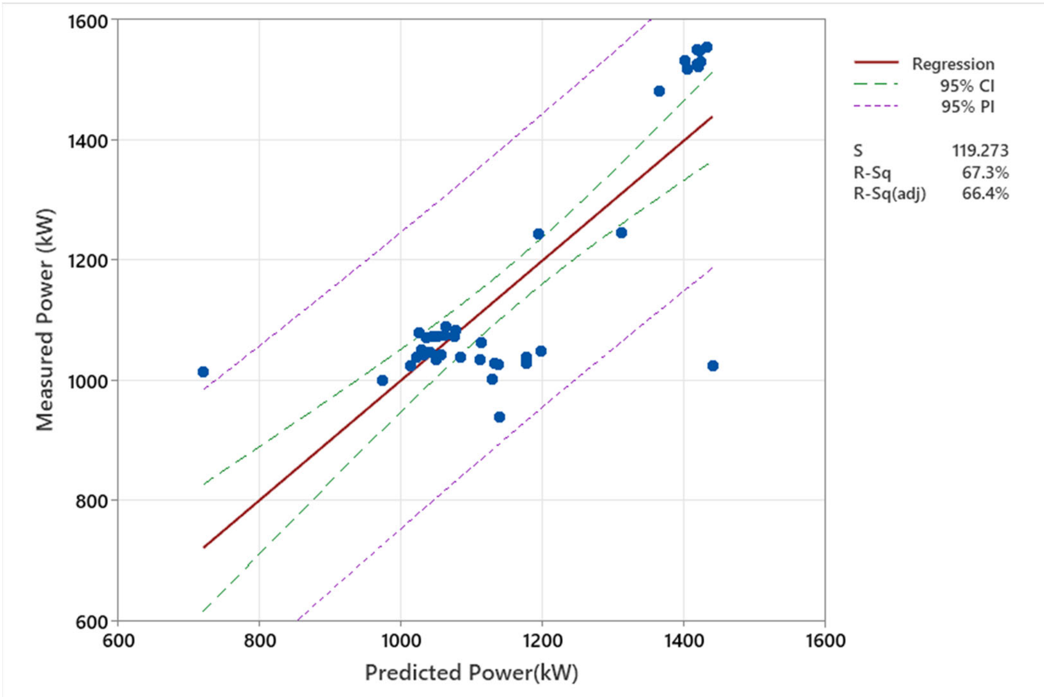


Figure 11—Scatter Plot of Measured and Predicted VRM Power

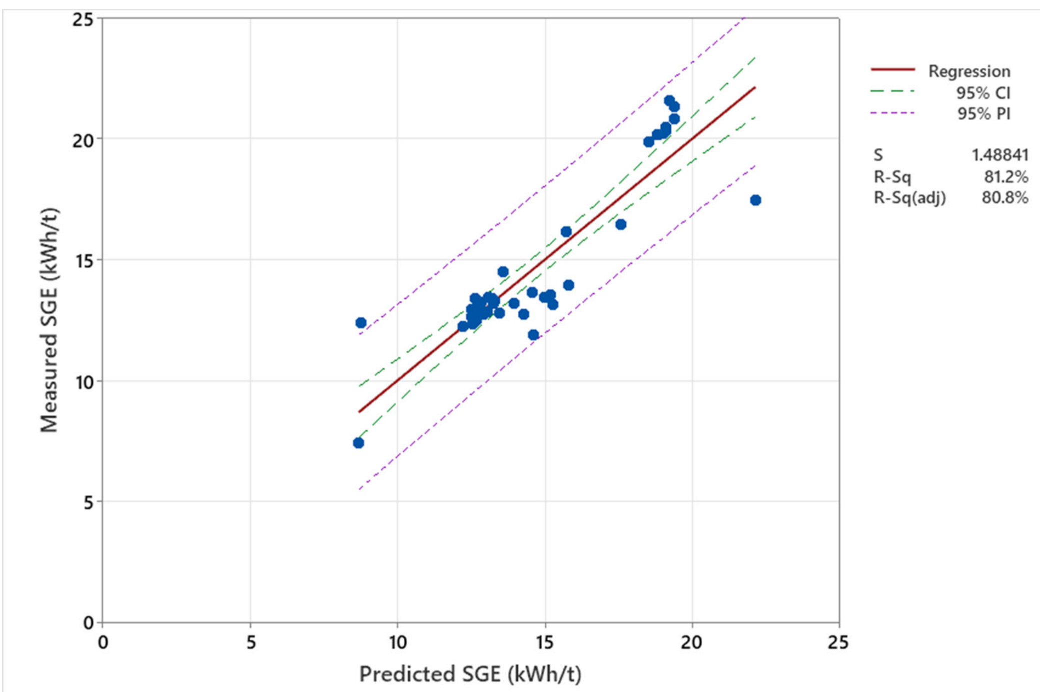


Figure 12—Scatter Plot of Measured and Predicted VRM SGE

## Conclusion

In summary, this paper describes the operational strategy of utilizing a single processing plant at Santa Elena mine for two distinct ores, the Santa Elena and Ermitaño ores, each with its own throughput and grind-size objectives. The paper highlights the challenge of accommodating varied operating conditions for the two ores and stresses the importance of a robust and flexible process flowsheet that can handle significant fluctuations in operating conditions. The paper highlights the operational flexibility of the VRM, a proven vertical stirred milling technology with a unique grinding mechanism. This technology is a key component enabling the Santa Elena process flowsheet to achieve the required operating flexibility with a goal of maximizing metal production. Furthermore, the paper shows the energy efficiency benefit of the VRM technology over the conventional ball mills, as evidenced by operating data gathered from Santa Elena mine. The multi-variable-based mill power draw model and SGE model serve as a practical tool for training, operational guidance, and future integration into the existing process control system using an empirical model-based controller. Going forward, the potential exists to install an additional VRM in tandem with the existing unit, to provide further expansion capacity at the Santa Elena mine.

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## References

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