Comparison of Industrial and Laboratory Grinding Specific Energies in Magnetite Ore Processing Using Donda's Approach

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Abstract. This study evaluates the grinding performance of two magnetite beneficiation plants operated by ArcelorMittal in Ukraine, with the aim of identifying opportunities to reduce energy consumption in comminution. An adaptation of Donda's methodology—a laboratory grinding procedure originally developed for itabirite ores from Brazil's Ferriferous Quadrangle—was selected as a diagnostic tool to compare laboratory-estimated specific energies with industrial values. The method relies on determining an ore-dependent parameter, K, from the relationship between cumulative oversize at a control screen and the specific energy applied at the mill pinion shaft. Representative samples from the primary, secondary, and tertiary grinding circuits of both plants were tested under adapted laboratory conditions, respecting the key principles of Donda's protocol. Industrial retained-mass values (RF and RP) were used to check whether laboratory-derived K values could approximate plant performance. The results show significant discrepancies, indicating notable potential for process improvement. Differences were most pronounced in the finer grinding stages, reflecting the increased difficulty of size reduction for higher-grade, finer concentrates. The outcomes demonstrate that Donda's methodology can effectively highlight inefficiencies in industrial grinding circuits, supporting targeted optimisation initiatives and potential reductions in energy consumption.

1. Context

ArcelorMittal has a global network of mining and steelmaking sites, supplying customers in 126 countries [1]. Committed to innovation and sustainability, ArcelorMittal owns 14 research centres (R&D) placed in Europe, North, South America and Asia [2].

With the growing global need for steel, having dependable, high-grade raw materials has become increasingly crucial. As one of the world's leading iron ore producers, ArcelorMittal relies on its own mines to ensure a consistent supply of top-quality ore for its steel production [3]. The Primary Department, part of Global R&D Maizières in France, aims to support the company's mining assets by optimizing existing processing routes and developing new ones.

This case study examines a beneficiation plant operated by ArcelorMittal in Ukraine, where the current process is being evaluated to reduce the energy consumption associated with comminution. For this purpose, *Donda's methodology*—a laboratory grinding test—was selected to assess the performance of the industrial grinding circuits. This methodology originates from a procedure used for primary grinding at the *Germano* concentrator operated by *Samarco Mineração* in Brazil [4]. Further details on *Donda's methodology* will be presented in a dedicated section.

2. Materials and Methods

2.1. Donda's methodology

This methodology was originally developed to estimate the grinding energy demand of itabirite ores from Brazil's Ferriferous Quadrangle. Donda [4] formalized the approach and demonstrated its strong correlation with industrial data, showing that the specific energy required at the ball mill pinion shaft can be calculated using Eq.(1), where [4], [5], [6]:

$$E = \frac{1}{K} * ln\frac{R_F}{R_P} \qquad (1)$$

E refers to the specific energy applied at the motor's pinion shaft (kWh/t), K is an ore-dependent constant defined for a given screen size (t/kWh). R_F represents the percentage of material retained on a selected screen in the feed, while R_P is the percentage retained on the same screen in the product. The parameter K is value characteristic of each ore type for a given mesh size and set of grinding conditions. Higher K values indicate

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greater grindability and improved grinding performance [4], [5], [6].

The laboratory determination of K is based on at least four grinding tests, with standardized parameters, using representative samples of the same ore, each subjected to a different specific energy level (within the industrially relevant range). The applied energy is calculated by dividing the power at the mill's pinion shaft by the test ore mass. The power itself is estimated using *Rowland's* equation for small-diameter mills, multiplied by the ball charge mass, as expressed in Eq. (2) [4], [5], [6]:

$$Kwb = 6.3 * \sin(51 - 22 * (\frac{(2.44-D)}{2.44})) * (3.2 - 3 * V_p) * C_s * (1 - \frac{0.1}{(2^{(9-10*C_s)})}) \quad (2)$$

The cumulative oversize mass at the selected screen for the feed and product streams is measured, and these data are then used to obtain the value of K through an exponential regression fit of Eq. (1) [4], [5], [6].

Whenever standardized laboratory tests are performed and the laboratory K values are compared with the industrial K values, if the industrial K is lower than the one obtained in the jar tests, it indicates that the industrial grinding process can be improved. In other words, if the energy consumed in the plant is much higher than the energy measured in laboratory tests, it means that the industrial energy use can be optimized [7].

2.2. Samples

The iron ores in this asset are associated with Banded Iron Formations (BIF) and have an average grade of approximately 36% Fe. Magnetite-rich ore extracted from two open pits supplies two beneficiation plants, A and B. Plant A produces an iron ore concentrate containing 65% Fe and 8% SiO_2 and D80 around 60 µm, while Plant B produces a concentrate with 68% Fe and 5% SiO_2 and D80 around 40 µm. Both plants achieve these grades through three stages of ball milling followed by magnetic separation (Figure 1).

The feeds of the three grinding circuits were sampled (indicated in the Figure 1) to perform the grinding laboratory tests. Industrial data, such as mass balance and operational variables were shared by the plant.

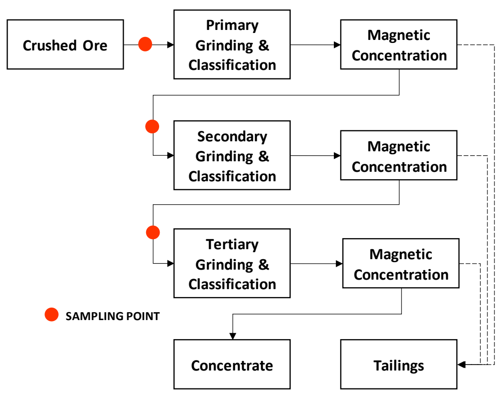

Figure 1. Schematic view of processing stages

Because Donda's methodology was originally developed for a specific ore and grinding circuit [7], some operating parameters—such as mill speed, mill filling, and others—do not fully match the conditions of the process evaluated here. Therefore, adaptations were required, integrating the plant's actual operating variables into the original testing protocol, except for the primary grinding stage. The primary grinding feed had to be crushed to 10 mm before testing, since its original size (D80 ≈ 20 mm) was much coarser than what is typically used in primary ball-mill circuits. The ball top size also had to be adjusted, as the industrial 120 mm balls are incompatible with the diameter of the laboratory-scale mill.

The objective with these tests were to compare the industrial expended energy with the laboratory estimated energy, like it was mentioned: *"if the energy consumed in the plant is much higher than the energy measured in laboratory tests, it means that the industrial energy use can be optimized"* [7].

To evaluate the grinding performance, the percentage of material retained in each control screen of both feed (R_F) and product (R_P) of industrial case was based on the mass balance of the plant. The R_F and R_P were the industrial values since it was wanted to compare if the K found in laboratory was comparable to the industrial K (the deviation is in the order of 10% [7]). If this hypothesis is true, then the energy calculated using Eq. (1) would approximate the industrial energy.

Table 1 presents some industrial data and the tests parameters adapted to the industrial case are presented on Table 2, Table 3 and Table 4.

Table 1. Industrial Data

Grinding Circuit	Control Screen (µm)	*Rf (%)	*Rp (%)
1ary (A)	212	93.4	17.2
2ary (A)	75	44.1	16.6
3ary (A)	53	27.3	12.2
1ary (B)	212	93.4	17.2
2ary (B)	53	62.6	27.3
3ary (B)	38	38.7	22.6

*Mass Balance reconciliation

Table 2. Primary grinding tests parameters

Plant Parameter	A	B
	Primary Grinding	
Mill inner diameter (m)	0.30	
Mill inner length (m)	0.30	
Mill load (%)	38.0	38.0
wt.% solids	77.4	77.2
% of critical speed	77	79
Energy on pinion shaft (kWh/t)	5, 8, 12, 15	5, 8, 12, 15
Charge distribution	**Diameter (mm)**	**Proportion (%)**
	63.5	35.0
	50.8	41.0
	38.1	18.0
	25.4	6.0

Table 3. Secondary grinding tests parameters

Plant Parameter	A	B
	Secondary Grinding	
Mill inner diameter (m)	0.30	
Mill inner length (m)	0.30	
Mill load (%)	38.0	35.0
wt.% solids	65.3	65.1
% of critical speed	67	74
Energy on pinion shaft (kWh/t)	6, 9, 12, 15	6, 9, 12, 15
Charge distribution	**Diameter**	**Proportion**
	40.0 mm	29.5 %
	30.0 mm	38.0 %
	25.0 mm	20.2 %
	20.0 mm	12.3 %

Table 4. Tertiary grinding tests parameters

Plant Parameter	A	B
	Tertiary Grinding	
Mill inner diameter (m)	0.30	
Mill inner length (m)	0.30	
Mill load (%)	38	35
wt.% solids	57.3	58.1
% of critical speed	67	74
Energy on pinion shaft (kWh/t)	2, 4, 7, 8.5	2, 4, 7, 8.5
Charge distribution	**Diameter**	**Proportion**
	40.0 mm	29.5 %
	30.0 mm	38.0 %
	25.0 mm	20.2 %
	20.0 mm	12.3 %

3. Results

The laboratory tests results are depicted in Figure 2 and Figure 3. Both plots show the cumulative oversize percentage at the respective control screen in function of the energy (kWh/t) applied in the mill pinion.

Table 5 shows the laboratory K value for each grinding stage, the mill pinion energy and the estimated motor energy, considering 5% of energy loss.

It was expected to have closer K values for the primary grinding, since Rp and Rf for plant A and B are practically the same, as indicated in Table 1. This K difference can be explained by several errors, like industrial and laboratory sampling errors, tests execution errors, and the fact that the sample had to be crushed at 10 mm, influencing the ball mill breaking mechanisms.

On the other hand, K values for secondary (0.2357 – plant A and 0.1288 – plant B) and tertiary grindings (0.1631 – plant A and 0.1175 – plant B) indicate the difficulty of reducing the grains' sizes: as predicted, the concentrate with 68% Fe and 5% SiO_2 is finer, requiring more energy to be grinding, thus, presenting smaller K.

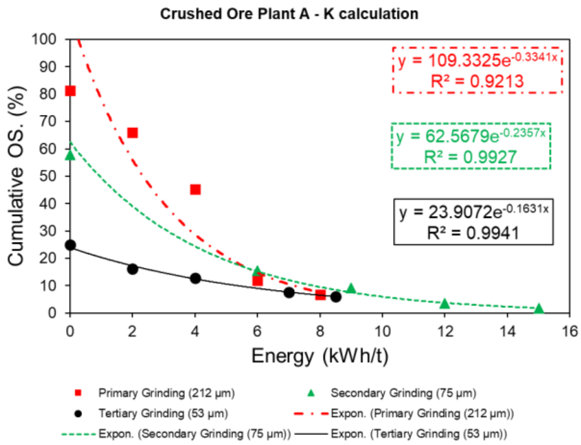

Figure 2. Curves for K calculation - Plant A

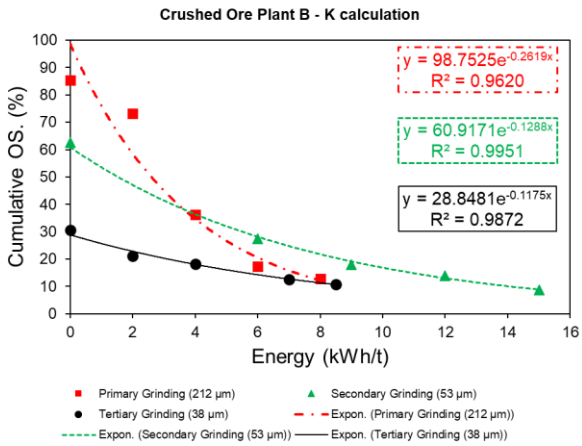

Figure 3. Curves for K calculation - Plant B

Table 5. Laboratory tests results

Grinding Circuit	K (t/kWh)	Mill Pinion Specific Energy (kWh/t)	Mill Motor Specific Energy (kWh/t)
1ary (A)	0.3341	5.06	5.33
2ary (A)	0.2357	4.15	4.36
3ary (A)	0.1631	4.94	5.20
1ary (B)	0.2619	6.46	6.80
2ary (B)	0.1288	6.44	6.78
3ary (B)	0.1175	4.58	4.82

If the hypothesis that the laboratory K was close to the industrial K, then the specific energies would approximate. When industrial specific energies are compared to the laboratory specific energies it is observed that the industrial K is far from the laboratory K values. The percentual difference between the industrial and laboratory specific energies consumptions for each stage were shared to stakeholders to discuss further improvement actions since the laboratory and industrial K diverge.

4. Conclusions

This study applied Donda's methodology to evaluate the grinding performance of two magnetite beneficiation plants. Laboratory-derived K values and specific energy estimates were compared to industrial values to assess the potential for reducing comminution energy consumption.

The results show that laboratory-estimated specific energies are consistently and substantially lower than those measured in the plant. Such gaps suggest significant inefficiencies in the industrial grinding circuits. Differences were most pronounced in the finer grinding stages, reflecting the increased difficulty of size reduction for higher-grade, finer concentrates.

Overall, the findings demonstrate that Donda's methodology is a useful diagnostic tool for identifying optimisation opportunities. The substantial differences between laboratory and industrial energy values highlight the potential for improved process control, enhanced milling efficiency, and meaningful energy savings.

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