

## Nickel ore grinding energy determination

### *Determinação energética da moagem do minério de níquel*

#### **Alaine Moreira Imbelloni**

Ma, Professora Assistente, CEFET  
Araxá, Minas Gerais, Brasil  
alaineimbelloni7@gmail.com

#### **José Pedro Silva**

Engenheiro Especialista, Samarco Mineração S/A,  
Minas Gerais, Brasil  
pedro@samarco.com

#### **Carlos Alberto Pereira**

Dr. Professor Associado, Universidade Federal de  
Ouro Preto, Brasil  
pereira@demin.ufop.br

#### **Abstract**

*This study describes the application of an empirical method to estimate the energy consumption in laboratory of the primary grinding of nickel ore with a specific mineralogical texture. This method developed by Donda was previously used in iron ore from the Iron Quadrangle (Minas Gerais, Brasil) with the same purpose. Through the grinding test, performed under standard conditions and based on the degree of liberation and percentage retained on 0.074 mm, it is possible to obtain the energy consumption for grinding. The results mean a validation of the method with a good approximation between industrial and laboratory values. In practice the energy consumption is 26.6 kWh/t and through Donda's method, when using the liberation degree as a parameter, the energy found was 26.8 kWh/t.*

**keywords:** Energy consumption, Nickel ore, Donda's method

#### **Resumo**

Esse estudo descreve a aplicação de um método empírico para estimar, em laboratório, o consumo de energia de moagem primária do minério níquel com uma textura mineralógica específica. Esse método desenvolvido por Donda foi usado, anteriormente, em minério de ferro do Quadrilátero Ferrífero (Minas Gerais, Brasil), com a mesma finalidade. Através do teste de moagem, realizado com condições padronizadas e baseado no grau de liberação e na porcentagem retida em 0,074 mm, é possível obter o consumo de energia de moagem. Os resultados significam uma validação do método com uma boa aproximação entre valores industriais e laboratoriais. Na prática, o consumo de energia é 26,6 kWh/t e, através do método de Donda e usando o grau de liberação como parâmetro, a energia encontrada foi de 26,8 kWh/t.

**Palavras chave:** Consumo energético, minério de níquel, método de Donda

### **1. Introduction**

In mineral processing plants, the comminution process is carried out in order to reduce particle size and “unlock” the mineral species from the gangue, enabling enrichment of the mineral content to the desired level in subsequent concentration processes (WILLS, 2006).

Over the years, various comminution theories were created and were only concerned with the evaluation of the

relationship between applied energy and particle reduction. Despite all advances obtained in the knowledge of grinding, there is a gap about estimating the specific energy consumption. The laboratorial energy measurements require complicated assembly and specialized labor for the realization of tests. On other hand, studies in industrial plants require a large amount of material, take

a long time and have high costs.

Donda (2003) developed a method to estimate grinding energy consumption for ball mills using the iron ore concentrate from the Iron Ore Quadrangle (Minas Gerais, Brazil). Its applicability has been established for many years for the re-grinding stage at Samarco Mineração S/A showing a good approximation between industrial and laboratorial

energy values with a range between 0.9 and 1.1 times the value of the specific industrial energy consumption.

This method is an adaptation of the methodology proposed by Bogren and Wakeman, at the current Midland Research Center and consists of grindings using different times with standardized conditions for ball and ore charge, mill speed and solid percentage, calculating

the absorbed power per tonne of grinding media through the Rowland equation for a small mill (diameter until 0.76m). The use of this method means a simplification of the laboratory procedures as being the differentiating factor, since the tests can be performed in mills built with minimum care and are not requiring sophisticated equipment to measure the energy in the laboratory (Von Krüger,

2004)

Studies about the nickel ore showed that the liberation of nickel occurs in the size of fines (0.074 mm) and requires high power consumption in the primary grinding. Then, considering the importance of controlling this parameter, this study's main goal was to verify the applicability of the Donda's method for fine nickel ore.

## 2. Materials and methods

The experiments were done in the Laboratory of Mineral Processing at the University of Ouro Preto using a sample of nickel ore from the mine of Fortaleza de Minas belonging to Votorantim Metals Nickel S/A. The initial lot of material

was homogenized and quartered. The grinding tests were performed in a ball mill utilizing four different times (20, 40, 60 and 80 minutes) with standard conditions as shown in Table 1. For each test, the particle size analyses of the feed

and products were determined by wet screening using Tyler sieves. Chemistry analysis was performed with samples of the ground products using optical microscopy

Conditions for the Donda tests	
Mill diameter (m)	0.3048
Mill length (m)	0.3048
Ball charge (kg)	30.578
% critical mill speed	70
% of solids	81
Ore charge (kg)	5.623
Media charge	Balls
Ball size distribution (diameter) (63 to 25 mm)	Staggered

Table 1  
Pre-established conditions for the tests (Donda, 2003).

Using the Rowland equation (Eq.1), the power was obtained by

multiplying the (kWb) value by the ball load weight. The specific energy was

obtained multiplying the power by the milling time.

$$kWb = 6,3xD^{0,3} \times \sin \left[ 51 - 2 \left( \frac{2,44-D}{2,44} \right) \right] \times (3,2 - 3V_p) \times C_s \times \left[ 1 - \frac{0,1}{2^{(9-10C_s)}} \right] \quad (\text{Eq. 1})$$

Where:

$kWb$ = Kilowatts per tonne of balls

$D$ = Mill diameter inside lifters [m];

$V_p$ =Fraction of the mill volume oc-

cupied by the balls mill;

$C_s$ = Fraction of critical mill speed.

## 3. Results

### Mineralogical analyses

The Table 2 shows the results of the mineralogical analyses, which were done based on the optical microscopy using the

product of the milling test for 60 minutes. The samples used were composed mainly of amphibole, pyrrhotite, chlorite, mag-

netite and pentlandite.

Mineral	%	Mineral	%
Amphibole	39	Carbonate	3
Pyrrhotite	20	Biotite	Trace
Chlorite	12	Chromite	Trace
Pentlandite	11	Pyrite	Trace
Talc + White Mica/Sericite	6	Pyroxene	Trace
Magnetite	5	Goethite	Trace
Chalcopyrite	3	Ilmenite	Trace
Trace: < 1%			

Table 2  
Mineralogical analysis

According to the photomicrographs obtained by optical microscopy with transmitted light, it was possible to determine that pentlandite is normally

associated with pyrrhotite as revealed in Figure 1, which presented a flame of pentlandite (PDT) in pyrrhotite (PYR). The Figure 3 shows a pyrrhotite (PYR)

particle with pentlandite (PDT) flames and a pentlandite (PDT) particle with pyrrhotite (PYR) edges.

Figure 1  
grinding performed during 20 minutes

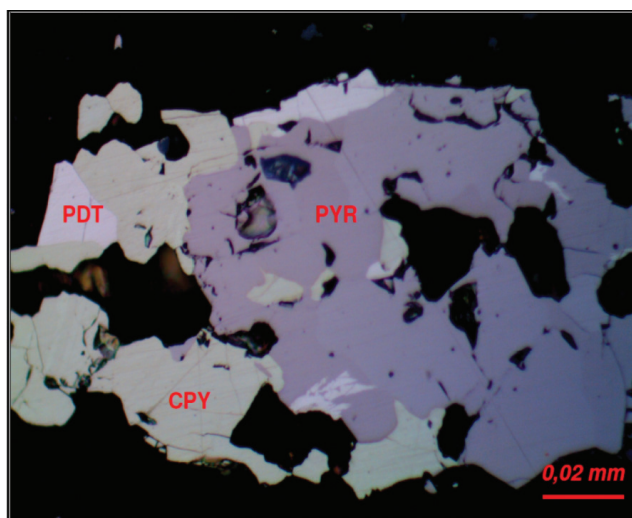
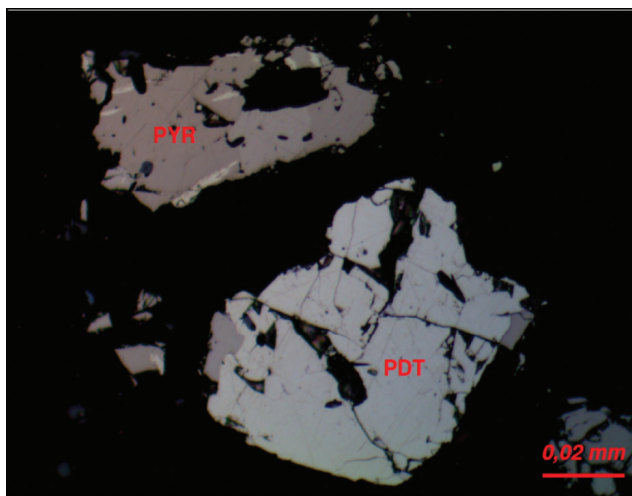


Figure 2  
grinding performed during 40 minutes

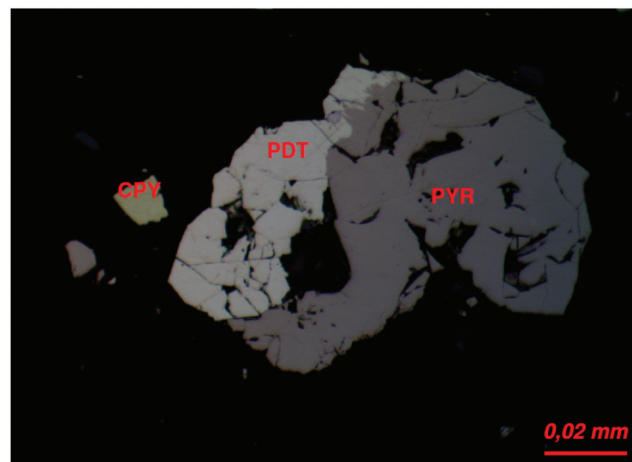


After 60 minutes of grinding, it was possible to notice the presence of a particle liberated from pentlandite (PDT)

and pyrrhotite (PYR) particle associated with pentlandite (PDT) as revealed in Figure 4. For the product of grinding

performed during 80 minutes, note the free particle composed of pentlandite (PDT) in Figure 5.

Figure 3  
grinding performed during 60 minutes



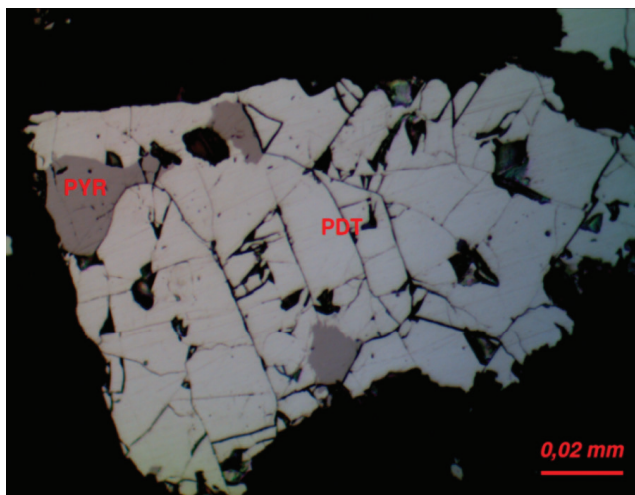


Figure 4 grinding performed during 20 minutes

### Granulometric analysis

Figure 6 shows the graph obtained from the particle size distribution of the feed and product for the grinding

tests. The results of P80, calculated as a function of the test time at 20, 40, 60 and 80 minutes were 0.210 mm; 0.140

mm; 0.125 mm and 0.096 mm.

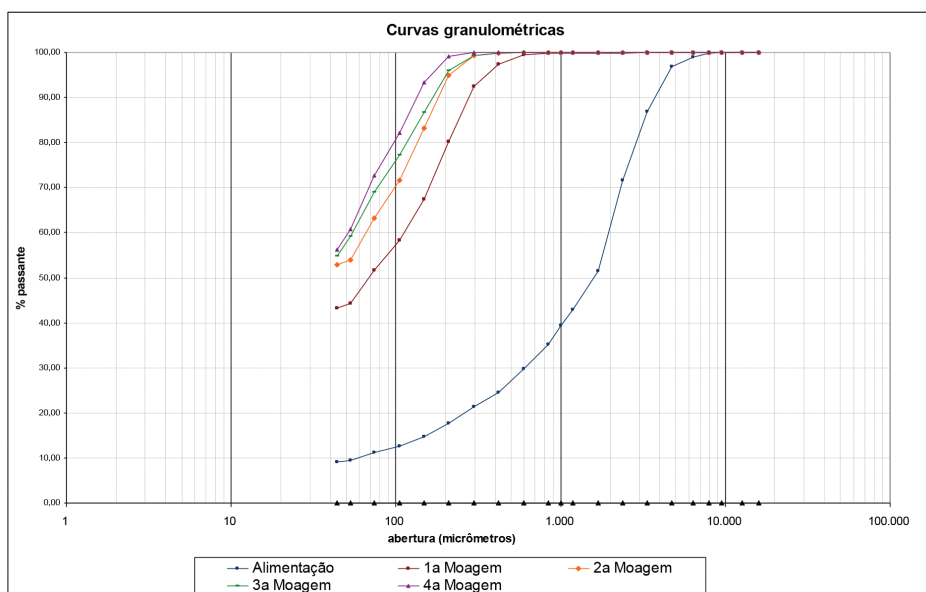


Figure 5 Particle size distribution

### Liberation degree

Calculation of the liberation was made by Gaudin, obtaining a particle size equal to 0.125 mm, assuming there is a variation of up to 3%. Therefore, the sequence of grinding time established for performing the assay was validated, since the interval of the P80 obtained contains the reference of the industrial practice.

The degree of liberation for each milling test was analyzed and results were 83.0%, 87.6%, 90.3% and 92.8%

for 20, 40, 60 and 80 minute milling, respectively.

Figure 6 shows the graph relating to the retained percentage on 0.074 mm, the liberation degree and the energy consumption.

According with the specification of Votorantim the primary milling should have 30% retained on 0.074mm for a flotation of 93%. From the graph analysis, the energy required for grinding, based

on the particle size distribution, for 30% retained on 0.074 mm was 21 kWh/t. The same verification in accordance with the liberation degree curve, showed an energy consumption of 26.8 kWh/t for 93%.

The measurements made by both parameters were very close, but for industrial practices, the highest value should be adopted as the determining parameter, in this case the liberation degree.

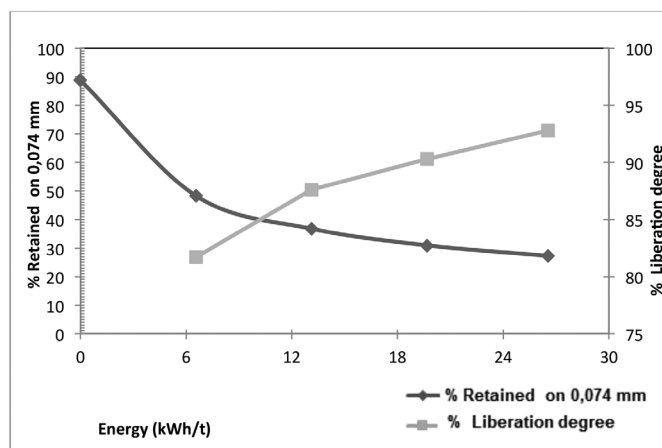


Figure 6  
Relation between the energetic requirement and the % retained on 0,074 mm.

#### 4. Conclusions

The results showed that the method used to estimate the specific energy consumption in industrial ball mills developed by Donda is applicable for the primary grinding stage of nickel ore with the typol-

ogy mentioned.

Industrial practice registers the necessity of a 93.0% degree of liberation to suit the subsequent flotation process. For this demand, in practice 26.6 kW/t

has been consumed. When using Donda's method and adopting the liberation degree as a parameter, the energy required was 26,8 kW/t, similar to the value obtained in practice.

#### 5. References

- BERALDO, J.L. *Moagem de minérios em moinhos tubulares*. São Paulo: Edgar Blücher, 1987. p. 1-47.
- BOND F.C., 1961. Crushing and grinding calculations. *Allis-Chaimers Publication*, No. 07R9235B (Revised).
- BULATOVIC, S.M. Handbook of flotation reagents: chemistry, theory and practice. Amsterdam: Elsevier Science & Tecnology Books, 2007. n.19 p. 401- 441.
- CARVALHO, E. A., SILVA, A. O., JUNIOR, J. B. R., BRENNER, T. L. B. *Níquel - Mineração Serra da Fortaleza. Usinas de beneficiamento de minérios do Brasil*. Rio de Janeiro: CETEM, 2001, p 295 – 303.
- CHAVES, A. P., PERES, A. E. C. *Teoria e prática do tratamento de inérios – ritagem, peneiramento e moagem* (3ª Ed.). São Paulo: Signus Editora, 2006. n.3.
- DONDA, J. D. *Um método para prever o consumo específico de na remoagem de concentrados de minérios de ferro em moinhos de bolas*. Belo Horizonte: Universidade Federal de Minas Gerais, 2003. (Tese de Doutorado apresentada ao Curso de Pós-Graduação em Engenharia Metalúrgica e de Minas - Área de concentração: Tecnologia Mineral).
- KRÜGER, F. L. *Corpos moedores côncavos*. Belo Horizonte: UFMG, 2004. (Tese de Doutorado em Engenharia Metalurgica de de Minas).
- MAN Y.T. A model-based scale-up procedure for wet, overflow ball mills. Brisbane, Australia: The University of Queensland, 2000. (Ph.D Thesis).
- WILLS, B. A., NAPIER-MUNN, T.J. Mineral processing technology. An introduction to the practical aspects of ore treatment and mineral recovery. (7ª, ed). Elsevier, 2006.

Received: 01April 2013 - Accepted: 08 May 2014.