Valorization of mining waste from Ouenza iron ore mine (eastern Algeria)

http://dx.doi.org/10.1590/0370-44672016700051

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Abstract

The present article is devoted to the development of a hematite-poor ore mine in Ouenza, which does not meet the steelmaker's requirements. Significant volumes are stored at the pithead of the mine, and the reserves are estimated at over 100 million tones. This enormous quantity of mining waste occupies an important space and poses a real threat to the environment as well as for the mining city of Ouenza. In order to solve these socio-economic and environmental problems, a sustainable development and a better quality of life for inhabitants of this region is needed. For this, representative samples were taken at the level of the dumps. Taking into account the natural characteristics of the stock namely; mineralogical composition, iron content, particle size of the rock mass, as well as the release mesh of iron minerals from the gangue. Firstly, tests are conducted on the recovery by radiometric separation of iron-rich pieces and graded. Then the rest of the ore was subjected to mechanical preparation followed by enrichment, which will be the subject of another study. The research is conducted on samples to determine the optimal parameters of the γ-rays absorption tested by radiometry; these parameters were the velocity of the conveyor belt and the time of exposure to γ-rays. The obtained results by this valorization process are very significant: iron content 53.5% and 8.3% recovery.

Keywords: linear absorption coefficient, Ouenza iron ore, radiometric method, γ-rays.

1. Introduction

The mine of Ouenza is located in the east of the country (see Figure 1), which is the main sourcing pole of iron ore for the Algerian steelmaking .The mine has suffered a decline in production of 2 million tons per year as a result of the quality mismanagement of the exploited raw materials. For this purpose, the rest of the extracted quantity represents low-grade ores of different iron contents, which are mainly hematite, goethite, limestone and sandstone. These poor ores are currently stored near the mine and the town of Ouenza.

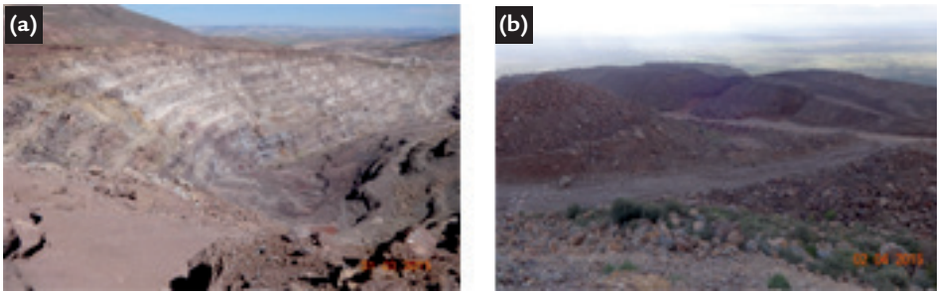

Figure 1
Ouenza Iron Mine.
a) View of the opencast mine,
b) Mining Waste

2. Materials and methods

This study relates to an oxidized iron ore concentration technology by radiometry - the case of Ouenza iron mine. This concentration process is based on the difference between the radiometric properties of mineral components, that is to say, their ability to emit, to reflect, and to absorb corpuscular radiation and ondulaires (Mokrousov and Lileyev, 1979).The linear absorption coefficient depends on the density of the medium, the mineralogical composition and the wavelength γ passing through a path unit. The samples taken from iron ore and waste rock have different mineralogical compositions, so they have different linear weakening coefficients.The study of the mineralogical composition of samples of iron ore and waste rock is performed by metallographic microscopy on polished sections (Table 1).Chemical analysis by XRF (Table 2) show the poor grade of the mine iron ore (Idres and Bounouala, 2005).

Minerals	Content, %									
	H	G	H G	SA	D	C	Q	A	M A	Others
Hematite	12.18	40.29	29.17	8.07	1.56	4.12	2.41	0.08	0.12	2.00
Goethite-Hydrogoethite	3.09	19.38	50.17	7.79	3.35	5.13	9.05	0.12	1.05	1.57
Limestones	0.17	0.28	0.97	-	-	94.37	1.30	-	-	0.73
Sandstone	-	0.39	0.27	-	-	3.29	94.92	-	-	0.32

H - Hematite, G - Goethite, HG - Hydrogeothite, SA - siderite-ankerite,
D - Dolomite, Calcite C-, Q - Quartz, A - Apatite, MA - Clay minerals

Table 1
Mineral composition of mining waste rock flancs of Ouenza mine.

Minerals	Content, %												
	Fe_{tot}	SiO_2	Al_2O_3	CaO	MgO	MnO	Mn	K_2O	Na_2O	P_2O_5	S	CO_2	PAF
Hematite	54.00	2.40	0.22	6.83	1.67	0.94	0.70	0.03	0.02	0.03	0.035	6.60	10.70
Goethite-Hydrogoethite	41.70	22.50	0.30	13.35	1.06	1.85	1.43	0.03	0.19	0.06	0.02	6.20	18.10
Limestones	0.90	2.00	0.16	52.85	0.55	0.08	0.07	0.02	0.06	0.01	0022	42.40	42.50
Sandstone	0.06	94.5	0.31	1.38	0.10	0.03	0.001	0.02	-	-	-	1.86	1.93

Table 2
Chemical analysis of mining waste of Ouenza mine.

2.1 Investigation of the influence of sample thickness on the absorption intensity of γ- rays

The influence of the thickness of the calibrated ore on the degree of γ-rays absorption, as well as that of the iron content of a calibrated sample, on the absorption intensity of γ-rays are performed at an installation laboratory (see Figure 2).

Once the devices are connected, we carry out measurements in a natural background (I_f) scintillation sensor (3), and then we record an initial intensity (I_0) of the γ-rays source (1) using a calculating device hotfix PC-20 (7).

Each operation is repeated three times, provided that the measurement time is greater than or equal to 10 seconds. Otherwise, the pulse recording accuracy decreases.

To increase the accuracy and to

stabilize the duration of the time interval during the measurements of the above parameters, we introduce timing relay (8) into the system illustrated in Figure 2.

The studied sample (2) is placed under the sights of the source of γ-rays. The latter, once they pass through the sample, are recorded by the scintillation counter (3). They are transformed into light signals, multiply and pass to the input of the radiometer (4). In the last, a signal forms according to the frequency; in other words, it depends on the intensity of γ-rays under the pulses per time unit (8), which excludes the measurement errors.

As a source of γ-rays (1), we use 153 Gadolinium, Thulium the 170, Americium 241, Cesium-137, and as an indicator of γ-rays, we use crystal thickness NAJ activated by Thallium. A radiometer of the components is integrated RC-circuit.

The measurement of γ-rays is based on the potential created by the charge of counting pulses in the integrated circuit (Azaryan, 2015).

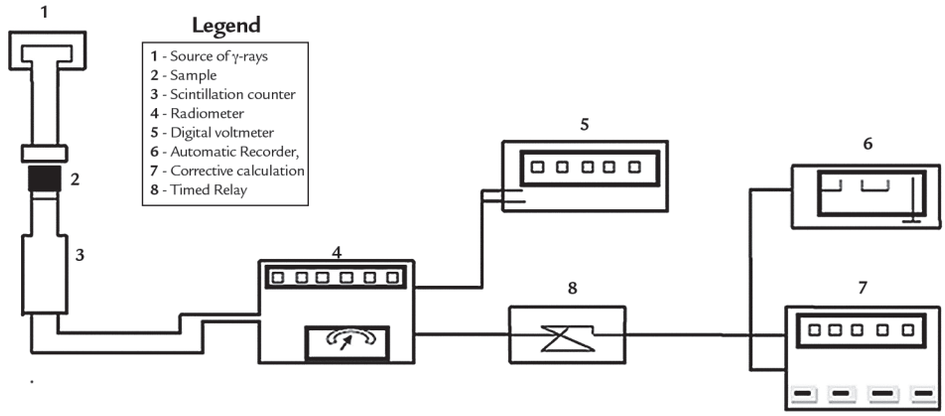

Figure 2
Installation for measuring absorption of γ-rays.

2.2 Measuring the intensity of γ-rays on the sample thickness

In the present study, the thickness of the sample analyzed is determined from the average of five (5) tests conducted. According to several researches (Medhat, 2012; Medhat, 2012; Kucuk *et al*., 2013), it was shown that the iron content, the mineralogical composition and the sample thickness directly affects the degree of absorption of γ-rays.

For more information on the influence of different factors cited above, laboratory tests were conducted on samples of varying size, and the absorption intensity was studied using various energy sources ie Gadolinium 153 and Americium 241.

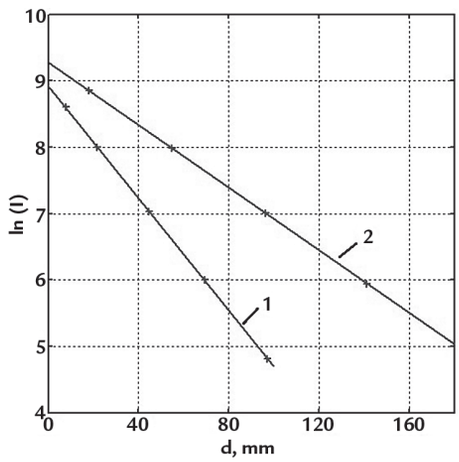

Figure 3
Influence of the intensity of γ-rays on the sample thickness. (Gamma source: Gadolinium 153)
1.Hematite, 2. Gangue

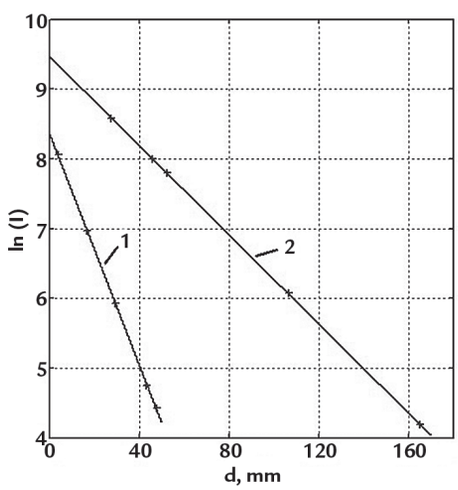

Figure 4
Influence of the intensity of γ-rays on the sample thickness (Gamma source: Americium 241)
1. Hematite, 2. Gangue

From the results obtained and shown in Figures 3 and 4, we note that the ray absorption intensity γ with a source of Gadolinium 153 and a variable thickness of the sample shows that with thickness equal to 80 mm, hematite minerals absorb approximately twice as many γ-rays as the gangue and the separation efficiency is significantly between 5.5 and 7.5. On the other hand, expected outcomes with Americium 241 demonstrate that the optimal size is reached at about 40 mm when I varies between 5 and 8.

2.3 Analysis of the effect of the absorption degree of γ-rays on the nature of the minerals

The absorption of γ-rays by different minerals is mainly characterized by the coefficients, such as linear, atomic and electronic.

The total absorption coefficient is most appropriate for the calculation of physical parameters. It is defined as the ratio between the linear absorption coefficient and absorption density (Medhat, 2011; Morkun and Tron, 2014).The linear absorption coefficient depends on the density of the medium, its mineralogical composition and the quantum wavelength γ penetrating through the path unit (Baştuğ *et al*., 2010).

The tested samples of different mineralogical composition are characterized by their difference of linear absorption coefficients (Manohara *et al*., 2010).

The intensity of the beam of γ-rays passing through a sample is determined by:

$$I_1 = I_0 \cdot e^{-\mu_1} \quad (1)$$

$$I_2 = I_0 \cdot e^{-\mu_2 \cdot d_2} \quad (2)$$

I_0 : primary radiation intensity;

I_1, I_2: intensity of radiation passing through the sample;

d_1, d_2: thickness pieces of the sample;

μ_1, μ_2: linear coefficient of absorption of γ-rays.

The γ-rays are easily absorbed by the mineral substance and can penetrate through solid bodies with a thickness of several centimeters. It is evident that the dependence of the total coefficient of γ-rays and the mineralogical composition is observed under the photoelectric effect. (Özdemir and Kurudirek, 2009).

The energy of γ-rays makes it possible to quantify the mineralogical composition of the sample provided that the value of E ≤ 300 keV. For this purpose, we propose for mine iron waste a range of energy variation E = 50 ÷ 200 keV which ensures the photoelectric absorption and Compton scattering (Kopanev *et al*., 2007; Kurudirek, 2011; Morkun and Tron, 2014).

Furthermore, the obtained results for the linear coefficient of γ-ray absorption depending on the iron content for samples of size 80 mm are presented in Figure 5.

Notice that the γ value is closely related to the mineralogical and chemical nature of the studied sample: the more the sample is rich in iron content, the γ value increases but the energy absorption decreases. To the contrary, it consumes more energy absorption of γ-rays if the sample is low in iron.

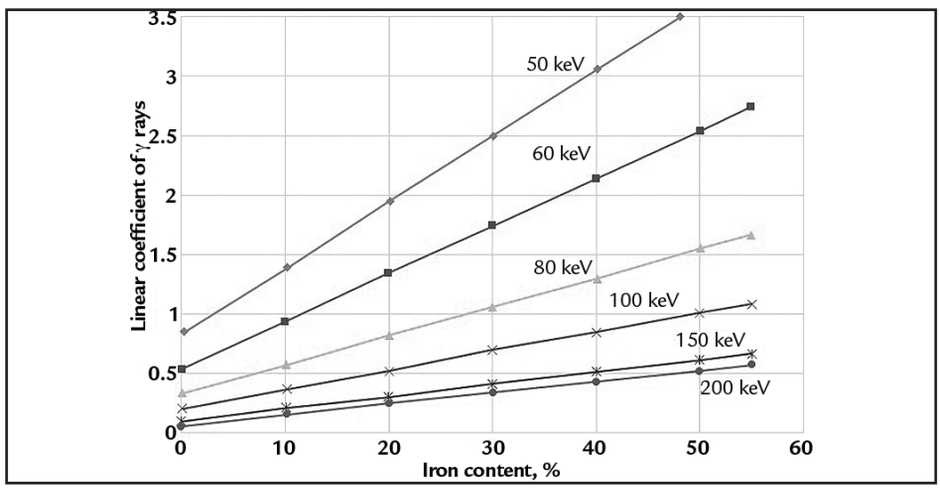

Figure 5
Influence of the linear coefficient γ on the iron content.

2.4 Study of minerals selectivity by means of adsorption of γ-rays

The ore separation curves make the option of a technological processing system possible, and facilitate the analysis and interpretation of results of the γ absorption process.

Knowing the size and composition from the fitness curves, possible theoretical values of treatment are determined (see Figure 6) based on:

- Φ curve to calculate the yield and reject content
- The curve λ, the elementary fraction,
- The curve β, the yield and the iron content in the concentrate,
- The curve μ_n, the separator accuracy.

To characterize the ability of the iron ore separation, we tested samples of size 50 ÷ 100 mm with an iron content of 37.8%.According to the obtained results, radiometric separation of iron ore is recommended. The iron recovery λ curve shows that the results obtained are highly significant (concentrate, intermediate product and rejects).

Separability curves (Figure 6) demonstrate that we can obtain from a sample studied: a 5.8% concentrate with an average iron content of 53.5% and 12% of schist with an iron content of 4.5% with permissible values of γ respectively 1.0 and 0.7 cm^{-1}.

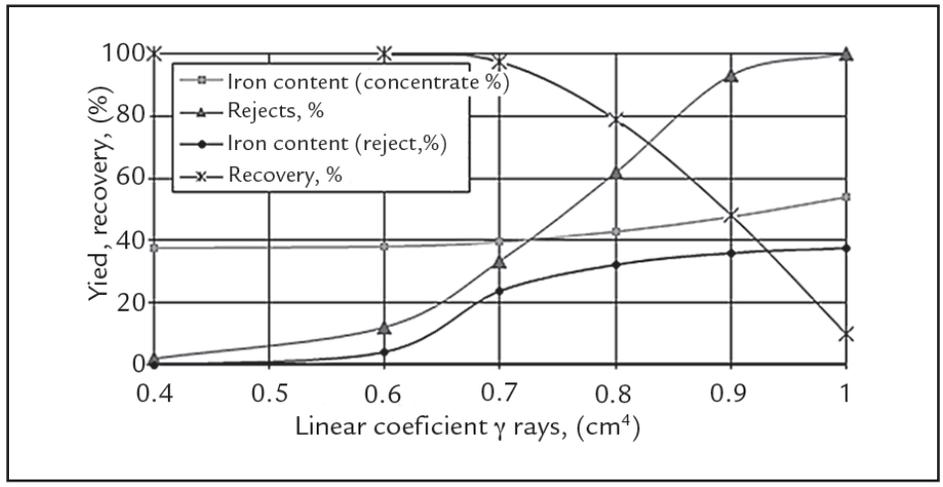

Figure 6
Effect of γ-rays on the calibrated ore (50 ÷ 100 mm).Furthermore, enrichment tests by radiometric separator with conical spreader are realized on the basis of the linear absorption coefficient variation of γ-rays (μ_n = 1.0 cm^{-1} and μ_n = 0.7 cm^{-1}).

As radiation source, we used the isotope Gadolinium 153 with an activity of 100 mCi. This one is recommended in scientific works already published (Chanturiya, 1993; Chanturiya, 1999; Morkun *et al.*, 2014).

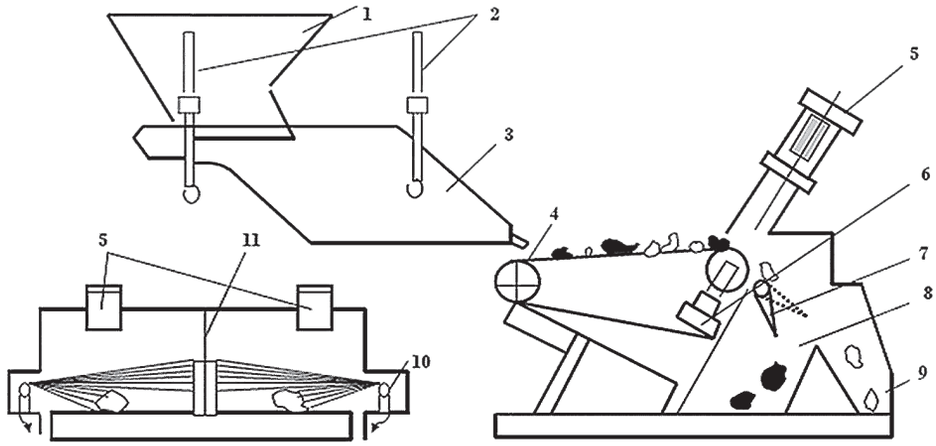

Figure 7
Scheme of radiometric separator with conical spreader.

1 - Receiving hopper, **2** - Lifting device, **3** - Vibrating Feeder,
4 - Conveyor belt, **5** - Gamma source, **6** - Scintillation sensor, **7** - Valve slide,
8 - Hopper for concentrated, **9** - Hopper for the gangue, **10** - Light Source, **11** - Obscure diodes.

2.5 Experimental section

This research work aims at studying the velocity effect of tape movement varying from 0.25 to 0.5 m / s and the exposure times of pieces ranging from 0.14 to 0.24 second. The achieved results of separation of the particle size fraction - 100 + 50 mm are shown in Figs 8 and 9 (for the first process radiometric) and in Figures 10 and 11 (for the second purification process).

When we vary the speed of the conveyor belt and the value μ_n = 1.0 cm^{-1} is reached, an iron content of 53.0% is achieved against a recovery of 11% with optimal speed of 0.4 m/s (Figure 8).

When we vary the exposure time for pieces μ_n = 1.0 cm^{-1}(constant), we attained an iron content of 53.5% against a recovery of 14.5% with an optimal exposure time of 0.2 second (Figure 9) .

By analogy to the second process radiometric for μ_n = 0.7 cm^{-1}, an iron content of 44.2% is reached against a recovery of 94% with optimal speed of 0.4 m / s (Figure 10).

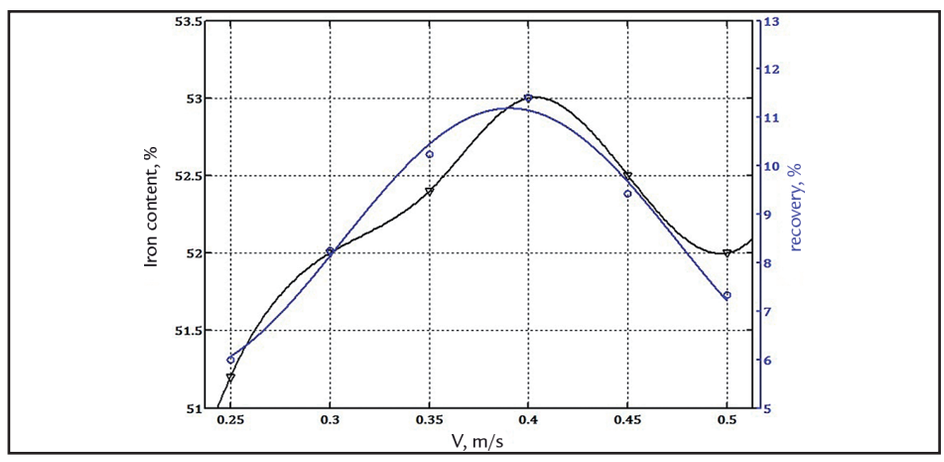

Figure 8
Effect of velocity of conveyor belt on the material balance for μ_n = 1.0 cm^{-1}.

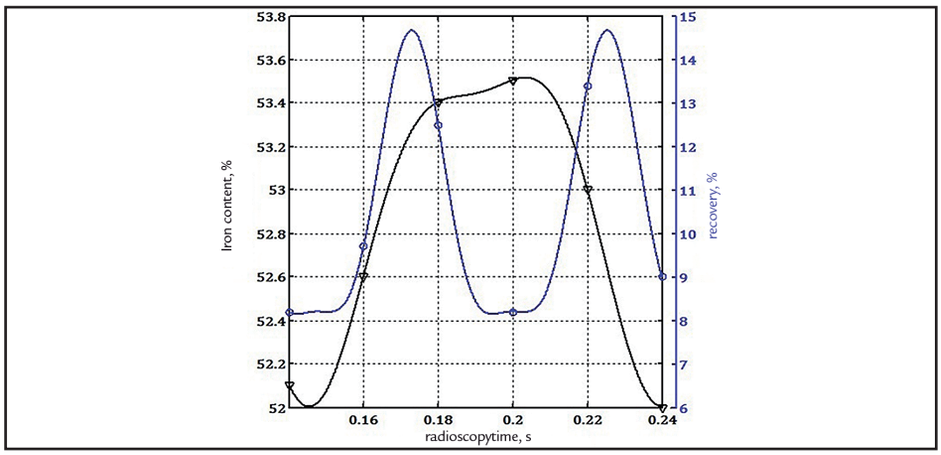

Figure 9
Effect of radioscopy time on the material balance for μ_n = 1.0 cm^{-1}.

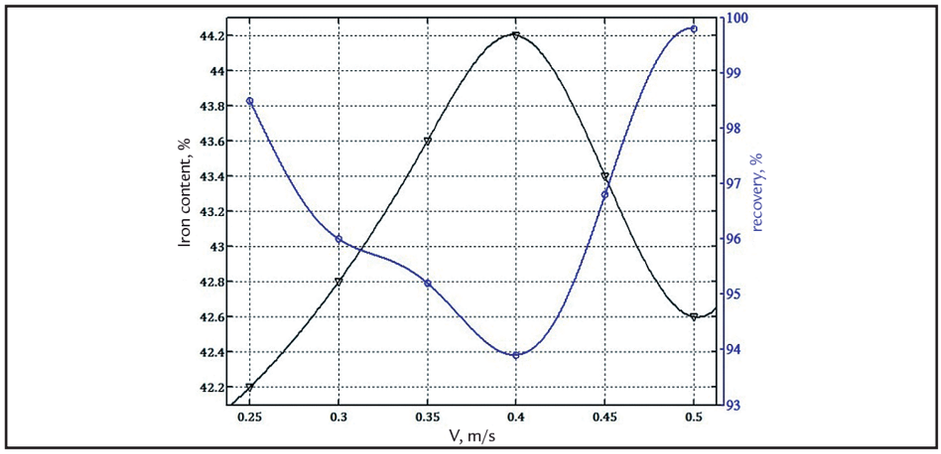

Figure 10
Effect of velocity of conveyor belt on the material balance for μ_n = 0.7 cm^{-1}.

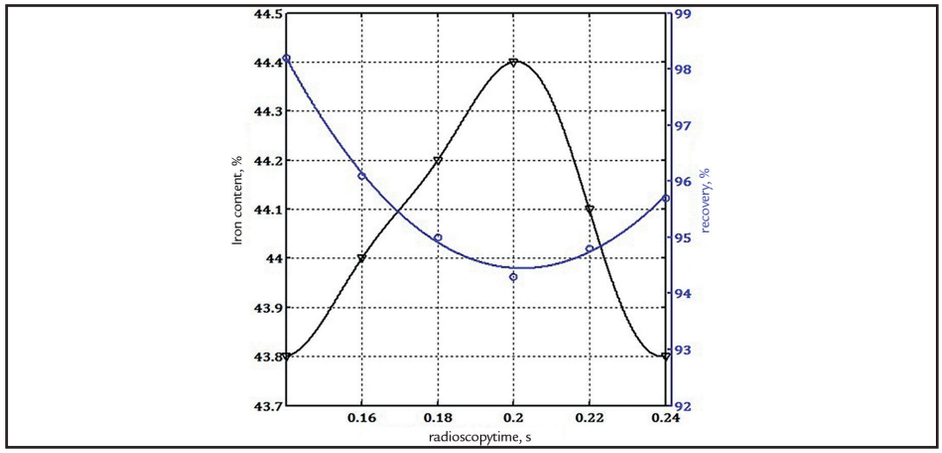

Figure 11
Effect of radioscopy time on the material balance for μ_n = 0.7 cm^{-1}.

3. Results and discussion

Corresponding to the research conducted in laboratory for a size fraction - 100 mm + 50 mm, the results obtained by radiometric separation are very encouraging. For this purpose, we suggest the flowsheet given in Figure 12.

However, after the first radiometric separation operation, we obtain a calibrated concentrate with a yield of 5.8% and an iron content of 53.5%. In the second operation, we obtain 12% of schist with an iron content of 41.2%.

In order to achieve the objectives referred in terms of radiometric separation efficiency, the first separation shall be set for μ_n= 1.0 cm-1 and the second operation for 0.7 cm^{-1}.

It results that the best separation system (first operation) for obtaining the concentrate with an iron content of 53.5% can be achieved with the following parameters: the limit value of linear weakening coefficient of γ-rays, μ_n= 1.0 cm^{-1}, the belt speed V = 0.4 m / s and the exposure time t = 0.20 second.

In this regard, in the second step of the radiometric separation, the material balance is notable in content and recovery when μ_n = 1.0 cm^{-1}, V = 0.4 m / s and t = 0.20 second. The rejects from the radiometric separation are of iron content of 4.5%.The products resulting from the screening operation and the second radiometric separation operation that are of poor quality (41% iron) will be subject for a preparation by crushing (optimal liberation mesh), followed by enrichment.

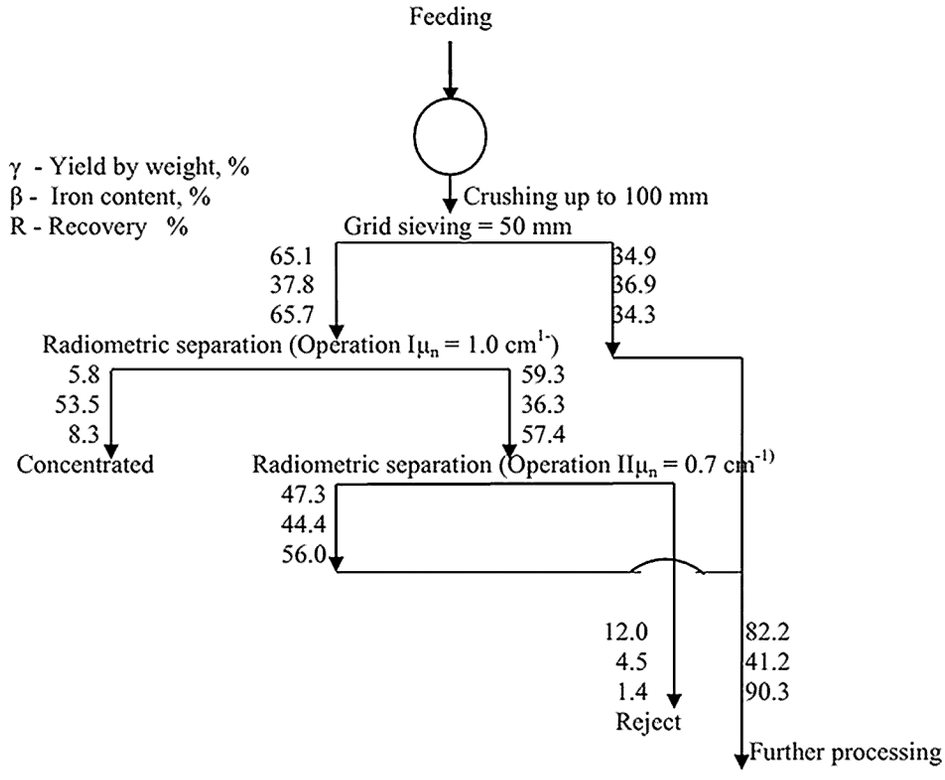

Figure 12
Schematic of radiometric separation proposed for mining waste from Ouenza mine.

4. Conclusions

According to the study carried out on the characterization and the possibility of radiometric separation of mining waste, the obtained results allowed us to draw the following conclusions:

- The particle size of the studied samples is between 50 and 100 mm to have calibrated pieces and facilitate the radiometric separation;

- A study of macroscopic size pieces allowed us to classify fractions into four mineralogical classes namely: hematite, goethite-hydrogoethite, limestone and sandstone;

- Chemical analysis of the different particle size fractions revealed that the iron content in hematite 54% against 41.70% in the fraction of the Goethite-hydrogoethite;

- Before proceeding to the samples separation, we used as a radiation source the isotope Gadolinium 153 and Americium 241;

- In the sample having a thickness of 80 mm, the hematite minerals absorbed approximately twice amount of γ-rays as the gangue did and the separation efficiency is significant for ionizing intensities varying between 5.5 and 7.5;

- Samples submitted to main radiometric separation (1st operation) reveal very significant results for recovery, and iron contents are 54% and 8% respectively (case of minerals rich in hematite);

- Rejects from the main separation, in turn undergo enrichment, where the obtained titrate concentrates have a content of 44% Fe with a recovery of 56%;

Finally, the concentrate from the final operation of radiometric separation, and after passing it through a sieve for a particle size of less than 50 mm, will be subjected to a characterization study for the selection of a separation process and enrichment.

Acknowledgments

The work presented in this article falls within the framework of a research project led by the Laboratory of Valorization of Mining Resources and Environment, Mining Department, Badji Mokhtar University, Annaba, Algeria. The entire research team thanks the Director, engineers and all staff of Ouenza iron mine (Algeria) for their help and contribution to carry out this research project.

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Received: 7 April 2016 - Accepted: 12 September 2016.