Практическая значимость. Результаты теоретических исследований использованы при создании лабораторных образцов оптического детонатора и в исследованиях срабатывания оптических детонаторов в зависимости от энергетических и геометрических характеристик лазерного луча.

Ключевые слова: *метод Монте-Карло, численный расчет, диффузно-рассеивающая среда, лазер, излучение, рассеяние, фотоны, взрывчатые вещества*

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VALORIZATION OF WASTE ROCKS FROM BOUKHADRA IRON ORE MINE FOR BETTER ENVIRONMENTAL MANAGEMENT

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ВАЛОРИЗАЦІЯ ВІДХОДІВ ГІРСЬКИХ ПОРІД ПРИ РОЗРОБЦІ РОДОВИЩА ЗАЛІЗНОЇ РУДИ БУХАДРА ДЛЯ ВДОСКОНАЛЕННЯ ЗАХОДІВ ІЗ ЗАХИСТУ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

Purpose. Characterization of mining wastes for the valorization of waste rocks from the Boukhadra iron ore mine which is located near the Algerian-Tunisian border in the city of Tebessa (Algeria).

Methodology. Analyses by X-Ray Diffraction, petrographic studies on thin sections and polished sections, particle size analysis, analysis by X-ray Fluorescence of the raw sample including those for the different particle size of waste rocks of the Boukhadra mine were carried out to identify their mineralogical and chemical composition. Based on the physical properties of these mining wastes, magnetic susceptibility was taken into account for possible enrichment of the weakly magnetic iron minerals by high intensity magnetic separation on dry way (DHIMS). During the separation of wastes, we took into account the particle size distribution and the intensity of the electrical current.

Findings. The studies realized have enabled us to deduce that the Boukhadra waste rocks, which are generally extracted from the open-pit mine, mainly consist of limestone, hematite, gray and yellow marls, with an average grade in Fe_2O_3 of 19.97 %. The particle size analysis carried out on a representative sample of the waste rocks from the Boukhadra mine weights 500 g and crushed to 4 mm reveals that the iron-rich class (27.67 % Fe_2O_3) is located between -0.5 + 0.25 mm. Tests by dry high-intensity magnetic separation on different classes: (-1 + 0.5 mm), (-0.5 + 0.25 mm), (-0.25 + 0.125 mm) and (-1 + 0.125 mm) with alternatives amperages (3–12 A) show that the experiment carried out in the class (-0.5 + 0.25 mm) at 12 A offers a concentrate of iron (40 % Fe_2O_3) against a reject of limestone and marls (43 % CaO, 15 % SiO_2, 8 % Al_2O_3, 2 % Fe_2O_3).

Originality. This is a topical issue in the Algerian mining industry, which causes serious problems for the mining environment and local residents following the increase in volumes of mining wastes and their pollution in the Boukhadra region. So, the management of waste rocks represents a major preoccupation for protecting the environment and contributes to the sustainable development. It represents a model for the valorization and the management of waste rocks from this mine or any other iron mine.

Practical value. The installation of mining wastes enrichment equipment allows, on the one hand, the recovery of a marketable product and, on the other hand, the rejects resulting from magnetic separation (DHIMS) can be used in various fields, namely: cement plants, ceramic, construction materials (economic interest), it will also contribute to the rehabilitation of the mining site and the protection of the environment.

Keywords: *Boukhadra, magnetic separation, mining wastes, sustainable development, valorization*

Introduction. Compared to all the activities of the national economy, the mining sector is the driving force for the sustainable development; technological fields are consumers of metal pieces (construction, automotive industry, various tools, agriculture, etc.) which are in turn based on iron ore. On the other hand, our environment, for a long time, has been affected by dangerous and very complicated problems, which results in the fallouts of volumes of mining wastes on the ecosystem. These wastes are deposited or stockpiled within the mine site and constitute a potential source of pollution because of their chemical characteristics and grain size [1].

The Boukhadra iron ore deposit situated in the north-east of Algeria is an excellent pole for supplying the iron and steel industry and a vital source of the employment and the development in the region. The deposit is mined using a combined method, underground and open pit. The extracted iron ore is characterized by a sufficiently high content; it is subsequently transported to the Annaba iron and steel complex for the elaboration of the cast iron and steel.

Waste rocks are defined as non-economic grades of rocks excavated to gain access to economic ore deposits [2]. It is known that, for a ton of iron ore, at least ten tons of mining wastes are extracted and they are put in-situ or in piles. These wastes hinder the exploitation process and local residents by their harmful effects on the environment (dust, landslides, water contamination, occupation of natural land, etc.); for example, six workers were killed on December 9th, 2006 when iron ore mining waste dumps collapsed in the Tollem mines in Goa, India [3].

Therefore, the valorization of these wastes is strictly necessary for the proper management of the waste rocks from the Boukhadra iron ore mine.

Overview on the Boukhadra mine. The Jebel Boukhadra is located in the east of Algeria, 45 km north of Tebessa City, 13 km from the Algerian-Tunisian border (Fig. 1). The iron deposit of Boukhadra is located in the mountainous area of Jebel Boukhadra, which belongs to the Atlas Saharan series and is characterized by a simple anticline structure of NE-SW [4].

The Boukhadra iron Deposit is operated by two methods: Open pit (by half-trench) and Underground (by slaughtered sub-levels). The transport of the iron from the mine to the gyratory crusher is carried out by trucks. After that, the crushed ore is transported through the belt conveyor to the homogenization station.

General information on mining wastes. Mining wastes include all solids, liquids, or gaseous substances rejected by the extraction, the preparation, the enrichment and the separation of the ore [5], these wastes can affect the environment through one or more of the following criteria [6]:

- chemical and mineralogical composition;
- physical properties;
- volume and surface occupied;
- waste disposal method.

The mining wastes from the Boukhadra mine consist of the waste rocks, the tailings (poor iron ore) besides the tailings resulting from crushing, transporting ore by belt conveyor or truck, homogenization, etc. The experts estimate that Boukhadra mining wastes have a total volume of about 30 million tons; these wastes are spread over an area of approximately 10 hectares.

Some examples of mining wastes and their reuse in addition to their recycling option are given in Table 1.

Presentation of the main research and methods. The characterization of Boukhadra's waste rocks represents a crucial phase which allows us to identify the mineralogical composition as well as their physical and chemical properties. It offers a forecast of its future influence on the environment.

In this study, samples of waste rocks were collected from various points of the waste rocks storage area of the Boukhadra mine. It should also be noted that these wastes originate mainly from the open pit mine. The mineralogical composition of the waste rocks in question is composed of limestone, iron ore, yellow and gray marls.

Mineralogical study of waste rocks. Petrographic Analysis. The petrographic analysis carried out on samples (thin sections and polished sections) allow us to identify the mineral phases of the Boukhadra mine waste rocks.

Table 1

Examples of reuse and recycling options for mining wastes [7]

Waste type		Examples of reuse and recycling option
Mining wastes	Waste rocks	Resource of minerals and metals, feedstock for cement and Concrete. Aggregate in embankment, road, pavement, foundation and building construction
	Mine waters	Recovery of metals from AMD waters. Generation of electricity using fuel cell technology
	Mine drainage sludges	Extraction of hydrous ferric oxides for paint pigments. Extraction of Mn for pottery glaze
Processing wastes	Tailings	Reprocessing to extract minerals and metals. Fe-rich tailings mixed with fly ash and sewage sludge as lightweight ceramics
Metallurgical wastes	Bauxite red mud	Raw material for glass, tiles, cements, ceramics, aggregate and bricks. Treatment of AMD waters
	Historical base metal smelting slags	Production of concrete and cement. Extraction of metals (e.g. Cu, Pb, Zn, Ag, Au)
	Phosphogypsum	Soil amendment. Building and construction material

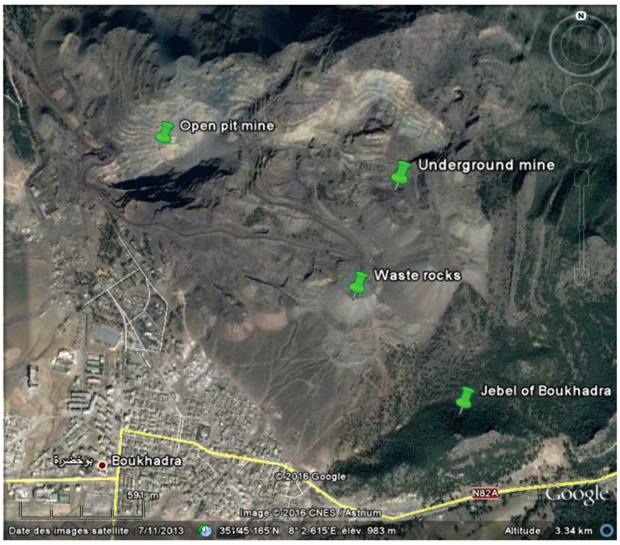


Fig. 1. Presentation of the study area

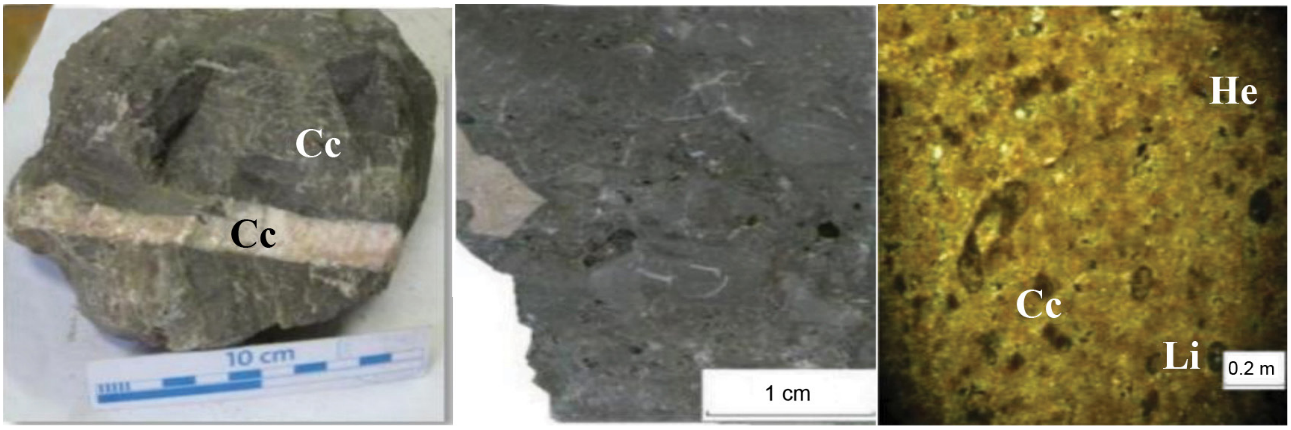
Gray limestone. Gray limestone with secondary calcite strands. The sample is intersected by filling of calcite (Fig. 2).

Iron ore. Iron ore partially altered into iron hydroxide. The sample shows numerous traces of alteration in the form of limonite veinlets as well as corrosion vacuoles filled with calcite (Fig. 3).

Gray marls. Gray marl, massive, with millimetric entanglements of acicular calcite. Some samples present leaching vacuoles (Fig. 4).

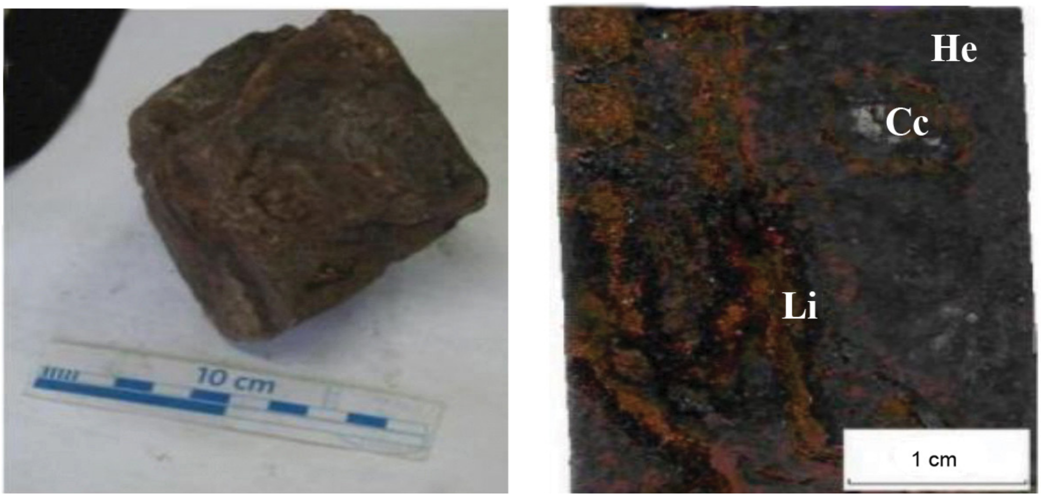
Yellow marl. Massive yellow marl with rare traces of iron hydroxides (limonite). The rock shows a lot of traces of oxidation and alteration (Fig. 5).

Qualitative analysis of waste rocks by X-rays diffraction. The analysis by *X-rays diffraction* of Boukhadra waste rocks down in the Office of Geologic and Mining Research (OGMR) – Boumerdes revealed the following minerals phases: Calcite, Quartz, Goethite and Hematite (Fig. 6).



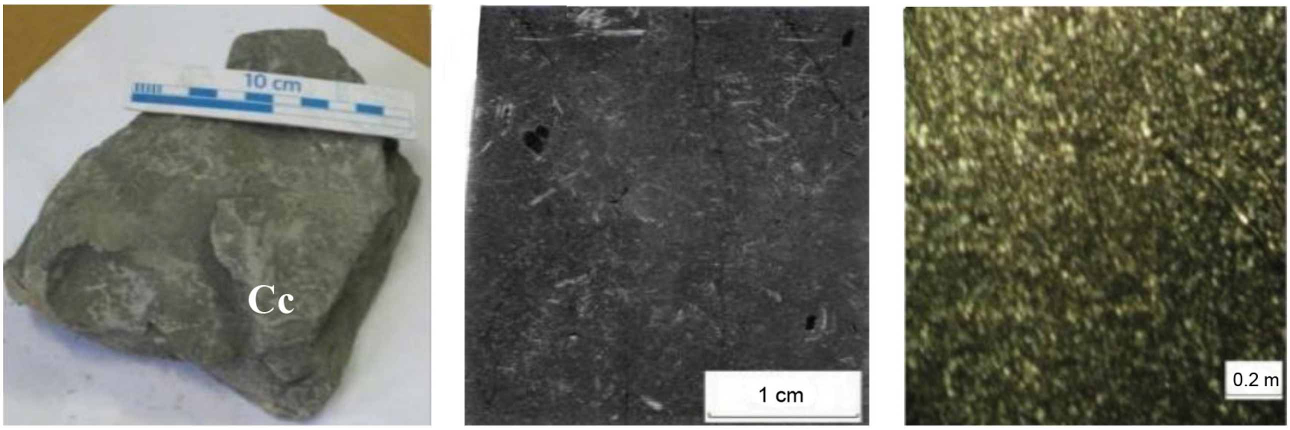
a *b* *c*

Fig. 2. Petrographic analysis of gray limestone:
a – gray limestone with secondary calcite strands; b – polished section of gray limestone; c – microphotography in polarized light analyzed from gray limestone with traces of iron oxides and hydroxides; Cc – Calcite; He – Hematite; Li – Limonite



a *b*

Fig. 3. Petrographic analysis of iron ore:
a – iron ore partially altered into iron hydroxide; b – the polished section shows many traces of alteration; Cc – Calcite; He – Hematite; Li – Limonite



a *b* *c*

Fig. 4. Petrographic analysis of gray marl:
a – photo of gray marl samples; b – polished section of gray marl showing leaching vacuoles and veinlets of filling calcite; c – microphotography in polarized-light analyzed from gray marl with traces of acicular calcite; Cc – Calcite

a *b* *c*

Fig. 5. Petrographic analysis of yellow marl:
a – massive yellow marl with rare traces of iron hydroxides; b – polished section with many traces of iron oxides and hydroxides; c – microphotography in polarized-light analyzed from gray marl with microscopic traces of iron oxides and hydroxides; He – Hematite; Li – Limonite

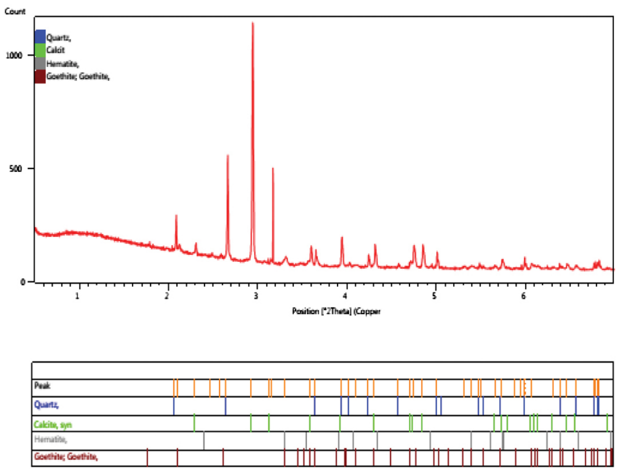


Fig. 6. XRD analysis of Boukhadra waste rocks

Physical and chemical characterization of waste rocks. Particle size analysis. The particle size analysis carried out on a sample of waste rocks of the Boukhadra mine crushed to 4 mm shows a high yield of 24.6 %; this was recorded in the class -4 + 2 mm. The results obtained are given in Table 2.

Particle size chemical analysis. The chemical composition of the waste rocks was carried out by the XRF analyzer in the Center of Study and Technological Services of Construction Materials Industry (CSTSCMI) – Boumerdes (Table 3). From the particle size analysis data, it seems that the waste rocks of the Boukhadra mine is rich in CaO (>34 %), especially the particle size classes -4 + 0.5 mm. The iron content exceeded 25 % in the classes -1+ 0.125 mm. The content of SiO_2 and Al_2O_3 varies in the particle size fraction not exceeding 21.21 % for SiO_2 and 6.51 % for Al_2O_3.

The purpose of the particle size chemical analysis is to obtain information on the hardness of the rock as well as the liberation size of the ore. For the Boukhadra waste rocks we estimate that the iron ore liberation size in relation to the rest is between the classes: -1+ 0.125 mm.

Fig. 7 shows the evolution of the contents of the main chemical elements constituting the Boukhadra waste rocks as a function of the particle size.

Valorization of the Boukhadra waste rocks by magnetic separation. Many processes have been used in the frame of the management and the valorization of mining wastes: magnetic separation, gravimetric separation, flotation, leaching, etc. (Idres, Abdelmalek, Bouhedja, Benselhoub and Bounouala, 2017) proposed a method for valorization of mining wastes of Ouenza mine (Algeria) by using radiometric separation [8].

Magnetic separation is one of the most common techniques used for concentration of diamagnetic and paramagnetic minerals; this process is used now for extracting minerals and metals from mining wastes. During the magnetic separation, the magnetic force developed inside of the magnetic separator could be expressed by the following formula, [9]

$$F_m = V \cdot M(H) \cdot \frac{dH}{dx}, \qquad (1)$$

where V is the volume of the magnetic particle, $M(H)$ is the magnetization of the magnetic particle in a magnetic intensity (H) and dH/dx is the magnetic gradients.

In view of the extraction of iron ore from all waste rocks of the Boukhadra mine, the high-intensity magnetic separator (HIMS) by dry method of the Valorization of Mining Resources and Environment Laboratory – Badji Mokhtar University – Annaba was used; this separator offers a magnetic flux density varying from 1.2 to 2 Tesla.

Results and discussion. ***Magnetic separation test results.*** The chemical analysis of the concentrate obtained by the magnetic separation tests was carried out at OGMR-Boumerdes, the values of Table 4 were calculated taking: Q_1 = 125 g.

With Q_1, Q_c and Q_r being, respectively, the masses of feed product, of concentrate and of rejects (g); α_i is iron content in feed (%); β_c and β_r are, respectively, the iron content in the concentrate and the reject (%); γ_c and γ_r are, respectively, the yields of concentrate and of reject (%); ε_c and ε_r are, respectively, the recovery of iron in the concentrate and the reject (%).

The results of the chemical analysis of two fractions (magnetic and non-magnetic) obtained after a test on the particle size class: -0.5 + 0.25 mm of the waste rocks from the Boukhadra mine with a variation in the intensity of the electric current of (DHIMS) of 12 A are given in Table 5.

The influence of the variation of the intensity of the electric current on the iron content (Fig. 8) and the recovery of the iron (Fig. 9) from the waste rocks of the Boukhadra mine is clear.

For grain classes: -1 + 0.5 mm, -0.5 + 0.25 mm and -1 + 0.125 mm, the recovery of iron increases when we increase the intensity of the electric current, the maximum value was obtained for the class: -0.5 + 0.25 mm tested at 12 A with; ε_c = 97.64 % in addition to Fe_2O_3 = 39.91 %.

A decrease in iron recovery was recorded for the class: -0.25 + 0.125 mm (Max: ε_c = 49.28 % and Fe_2O_3 = 32.62 % at I = 12 A). For this effect, a flow-sheet was proposed for the management and the valorization of the Boukhadra waste rocks (Fig. 10).

Conclusion. The volumes of mining wastes stored on the tile of the Boukhadra mine represent considerable reserves in mining wastes. These later cause air, water and soil pollution, which requires urgent solutions for the environmental management.

Table 2

Results of particle analysis of Boukhadra waste rocks

Particle size (mm)	Mass (g)	Mass (%)	Cumulated Refusals (%)
>4	60.3	12.06	12.06
-4+2	123.0	24.6	36.66
-2+1	92.6	18.52	55.18
-1+0.5	71.2	14.24	69.42
-0.5+0.25	69.7	13.94	83.36
-0.25+0.125	42.2	8.44	91.8
-0.125+0.063	21.2	4.24	96.04
-0.063+0.045	13.60	2.72	98.76
<0.045	6.2	1.24	100
Total	**500**	**100**	**-**

Table 3

Particle size chemical analysis of the Boukhadra waste rocks

Fraction (mm)	CaO	Fe_2O_3	SiO_2	Al_2O_3	MgO	K_2O	MnO	SO_3	TiO_2	Na_2O	P_2O_5	BaO	LOI
Initial	34.56	19.97	15.81	6.12	1.25	0.81	0.57	0.02	0.34	0.01	0.11	0.01	17.59
> 4	32.03	16.58	10.53	3.52	0.50	0.30	0.30	0.01	0.00	0.01	0.07	0.03	29.24
- 4 + 2	37.58	21.01	12.80	3.75	0.95	0.43	0.51	0.10	0.01	0.01	0.03	0.01	19.56
- 2 + 1	35.63	19.87	11.75	3.26	0.39	0.54	0.00	0.03	0.18	0.07	0.06	0.00	23.35
- 1 + 0.5	36.95	26.55	16.07	5.08	0.46	0.84	0.00	0.10	0.24	0.10	0.08	0.02	11.29
- 0.5 + 0.25	25.13	27.67	14.36	4.62	0.49	0.91	0.00	0.02	0.26	0.11	0.09	0.00	19.76
- 0.25 + 0.125	27.49	27.41	21.21	5.14	0.59	1.21	0.84	0.05	0.36	0.01	0.09	0.01	13.48
- 0.125 + 0.063	21.31	16.94	20.94	6.51	0.62	1.09	0.86	0.01	0.42	0.01	0.10	0.00	26.82
- 0.063 + 0.045	16.48	17.25	19.17	5.93	0.50	1.03	0.00	0.02	0.33	0.11	0.10	0.00	34.13
< 0.045	11.07	10.63	20.77	6.26	0.61	0.91	1.06	0.04	0.31	0.01	0.11	0.01	39.98

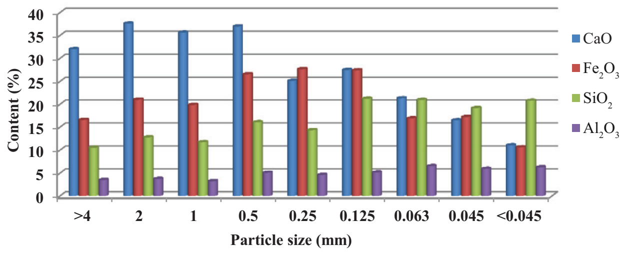


Fig. 7. Evolution of the contents of the major constituents according to the different particle size of the Boukhadra waste rocks

For further information, most of the waste rocks originate mainly from the open pit mine; they are constituted mainly by limestone, gray and yellow marls and hematite.

Physical and chemical characterization conducted on a representative sample shows that the waste rocks of Boukhadra have a medium grade of 19.97 % in Fe_2O_3.

The particle size analysis of a sample of the waste rocks from the Boukhadra mine weights 500 g crushed to 4 mm reveals that the iron-rich class (27.67 % Fe_2O_3) is situated between -0.5 + 0.25 mm.

Preliminary tests carried out by DHIMS on the same class at a variety of electrical intensities (3–12 A) show that the experiment conducted at 12 A offers a concentrate of iron (40 % Fe_2O_3) against a reject of limestone and marls (43 % CaO; 15 % SiO_2; 8 % Al_2O_3; 2 % Fe_2O_3).

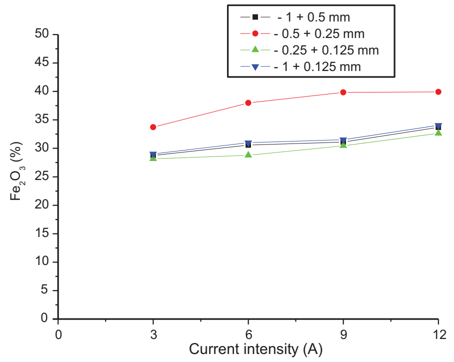


Fig. 8. Influence of the intensity of the electric current on the iron content

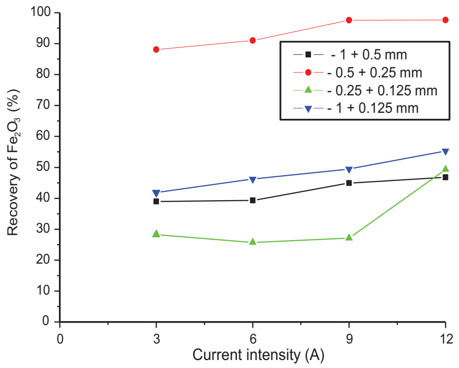


Fig. 9. Influence of the intensity of the electric current on the recovery of iron

Table 4

Tests by high-intensity magnetic separation of Boukhadra waste rocks

Class (mm)	Magnetic fraction				Non-magnetic fraction				Intensity (A)
	Q_c (g)	β_c (%)	γ_c (%)	ε_c (%)	Q_r (g)	β_r (%)	γ_r (%)	ε_r (%)	
- 1 + 0.5	45.02	28.74	36.01	38.98	79.98	25.31	63.99	61.02	3
	42.7	30.56	34.16	39.31	82.3	24.47	65.84	60.69	6
	47.93	31.10	38.34	44.91	77.07	23.72	61.66	55.09	9
	46.08	33.69	36.86	46.77	78.92	22.38	63.14	53.23	12
- 0.5 + 0.25	90.38	33.71	72.30	88.08	34.62	11.90	27.7	11.92	3
	82.88	37.98	66.30	91.00	42.12	7.38	33.7	9	6
	84.73	39.84	67.78	97.59	40.27	2.06	32.22	2.41	9
	84.63	39.91	67.70	97.64	40.37	2.02	32.3	2.36	12
- 0.25 + 0.125	34.35	28.17	27.48	28.24	90.65	27.12	72.52	71.76	3
	30.62	28.79	24.49	25.72	94.38	26.96	75.51	74.28	6
	30.53	30.46	24.42	27.13	94.47	26.42	75.58	72.87	9
	51.77	32.62	41.41	49.28	73.23	23.72	58.59	50.72	12
- 1 + 0.125	48.12	29.03	38.49	41.88	76.88	25.20	61.51	58.12	3
	49.73	30.98	39.78	46.19	75.27	20.74	69.22	53.81	6
	52.32	31.54	41.85	49.47	72.68	23.18	58.15	50.53	9
	54.18	34.04	43.34	55.32	70.82	21.03	56.66	44.68	12

Table 5

Chemical analysis of the rich class (-0.5 + 0.25 mm) tested at 12 A

Fraction	CaO	Fe_2O_3	SiO_2	Al_2O_3	MgO	K_2O	MnO	SO_3	TiO_2	Na_2O	P_2O_5	BaO	PAF
Magnetic (%)	3.97	39.91	4.05	2.57	0.21	0.46	0.76	0.04	0.26	0.05	0.01	0.02	39.91
Non Magnetic (%)	43.86	2.02	15.12	7.69	0.57	0.68	0.38	0.02	0.13	0.04	0.03	0.01	27.37

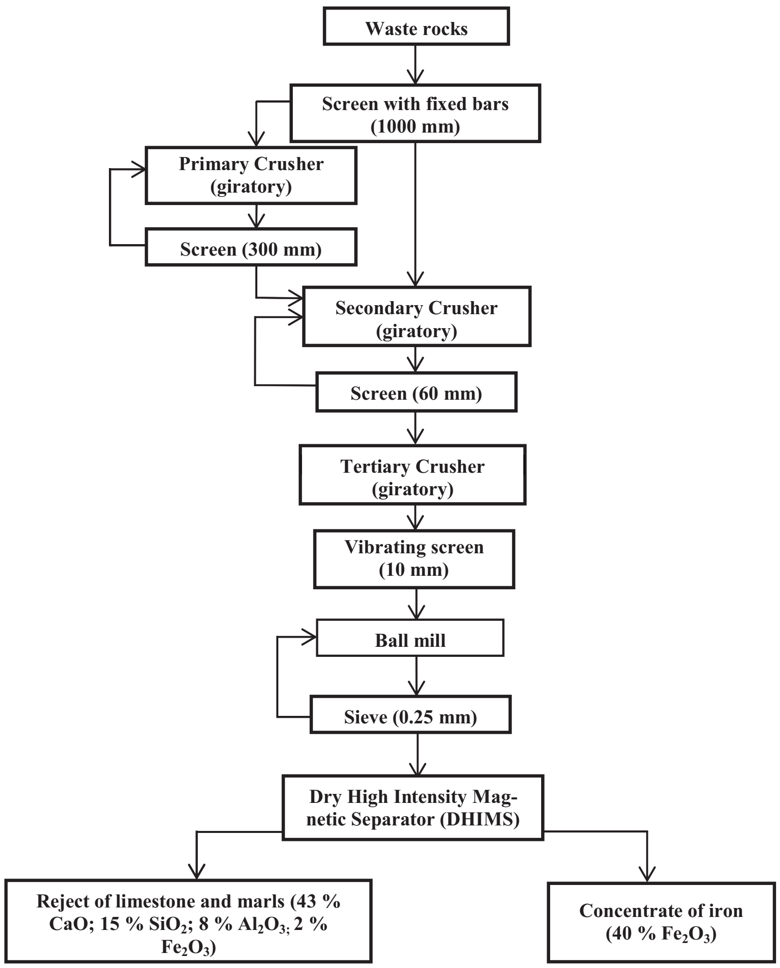


Fig. 10. Flow-sheet of valorization of waste rocks from the Boukhadra iron mine

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Мета. Збагачення відходів гірничої промисловості родовища залізної руди Бухадра, що розташовується поблизу алжиро-туніського кордону в місті Тебесса (Алжир).

Методика. Були виконані рентгенографія, петрографічні дослідження тонких зрізів і аншліфа, аналіз розміру частки, люмінесцентний аналіз проб сировини й різних класів крупності порід шахти Бухадра для визначення їх мінералогічного й хімічного складів. Вивчення фізичних властивостей цих порід дозволило використати магнітну сприйнятливість для виділення слабомагнітних залізовмісних мінералів шляхом сухої високоградієнтної магнітної сепарації (ВГМС). Під час поділу відходів ми враховували гранулометричний склад і силу електричного струму.

Результати. Проведені дослідження показали, що вміщуючі породи, вилучені із шахти Бухадра, в основному складаються з вапняку, гематиту, сірих і жовтих вапняних глин, із середнім вмістом Fe_2O_3 19.97 %. Аналіз розміру частинок, виконаний на типовій пробі вміщуючих порід шахти Бухадра, вагою 500 г і подрібненої до 4 мм, показує, що збагачений залізом матеріал (Fe_2O_3 27.67 %) розташовується у класі крупності (-0.5 + 0.25 мм). Дослідження сухою високоінтенсивною магнітною сепарацією різних класів крупності: (-1+ 0.5 мм), (-0.5 + 0.25 мм), (-0.25 + 0.125 мм) і (-1 + 0.125 мм) за різної сили струму (3–12 А), показали, що експеримент, виконаний на класі крупності (-0.5 + 0.25 мм) при струмі 12 А, дозволяє отримати магнітний залізовмісний продукт (40 % Fe_2O_3) при виділенні вапняку й вапняних глин (43 % CaO, 15 % SiO_2, 8 % Al_2O_3, 2 % Fe_2O_3).

Наукова новизна. Це актуальне питання для гірничорудної промисловості Алжиру, що створює серйозні проблеми для навколишнього середовища й місцевого населення у зв'язку зі збільшенням обсягів відходів гірничорудної промисловості в регіоні Бухадра. Тому використання вміщуючих порід є головною метою для захисту навколишнього середовища та сприяє сталому розвитку регіону. У роботі представлена модель валоризації та використання вміщуючих порід цієї шахти або будь-якого іншого залізорудної рудника.

Практична значимість. Встановлення в гірській промисловості обладнання для збагачення породи дозволяє, з одного боку, отримати додатково продукт, що відповідає ринковим вимогам, а, з іншого боку, виділити після магнітного поділу (ВГМС) продукт, що може використовуватися в різних областях, а саме: на цементних заводах, для виготовлення керамічних і будівельних матеріалів (економічний інтерес), що також сприяє рекультивації земель гірничодобувних майданчиків і захисту навколишнього середовища.

Ключові слова: *Бухадра, магнітне розділення, відходи гірничодобувної промисловості, сталий розвиток, валоризація*

Цель. Обогащение отходов горной промышленности месторождения железной руды Бухадра, расположенного вблизи алжиро-тунисской границы в городе Тебесса (Алжир).

Методика. Были выполнены рентгенография, петрографические исследования тонких срезов и аншлифов, анализ размера частицы, люминесцентный анализ проб сырья и различных классов крупности пород шахты Бухадра для определения их минералогического и химического составов. Изучение физических свойств этих пород позволило использовать магнитную восприимчивость для отделения слабомагнитных железосодержащих минералов путем сухой высокоградиентной магнитной сепарации (ВГМС). Во время разделения отходов мы учитывали гранулометрический состав и силу электрического тока.

Результаты. Проведенные исследования показали, что вмещающие породы, извлеченные из шахты Бухадра, в основном состоят из известняка, гематита, серых и желтых известковых глин, со средним содержанием Fe_2O_3 19.97 %. Анализ размера частиц, выполненный на типовой пробе вмещающих пород шахты Бухадра, весом 500 г и измельченной до 4 мм, показывает, что обогащенный железом материал (Fe_2O_3 27.67 %) располагается в классе крупности (-0.5 + 0.25 мм). Исследования сухой высокоинтенсивной магнитной сепарацией различных классов крупности: (-1+ 0.5 мм), (-0.5 + 0.25 мм), (-0.25 + 0.125 мм) и (-1 + 0.125 мм) при различной силе тока (3–12 А), показали, что эксперимент, выполненный на классе крупности (-0.5 + 0.25 мм) при токе 12 А, позволяет получить магнитный железосодержащий продукт (40 % Fe_2O_3) при выделении известняка и известковых глин (43 % CaO, 15 % SiO_2, 8 % Al_2O_3, 2 % Fe_2O_3).

Научная новизна. Это актуальный вопрос для горнорудной промышленности Алжира, который создает серьезные проблемы для окружающей среды и местного населения в связи с увеличением объемов отходов горнорудной промышленности в регионе Бухадра. Поэтому использование вмещающих пород является главной целью для защиты окружающей среды и способствует устойчивому развитию региона. В работе представлена модель валоризации и использования вмещающих пород этой шахты или любого другого железорудного рудника.

Практическая значимость. Установка в горной промышленности оборудования для обогащения породы позволяет, с одной стороны, получить дополнительно продукт, соответствующий рыночным требованиям, и, с другой стороны, выделить после магнитного разделения (ВГМС) продукт, который может использоваться в различных областях, а именно: на цементных заводах, для изготовления керамических и строительных материалов (экономический интерес), что также способствует рекультивации земель горнодобывающих площадок и защите окружающей среды.

Ключевые слова: *Бухадра, магнитное разделение, отходы горнодобывающей промышленности, устойчивое развитие, валоризация*

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