ФІЗИКА ТВЕРДОГО ТІЛА, ЗБАГАЧЕННЯ КОРИСНИХ КОПАЛИН

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A PRELIMINARY STUDY ON ANINI DEPOSIT IRON ORE ENRICHMENT (ALGERIA) IN ORDER TO USE IT IN METALLURGICAL INDUSTRY

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ПОПЕРЕДНЄ ДОСЛІДЖЕННЯ ЗБАГАЧЕННЯ ЗАЛІЗНОЇ РУДИ РОДОВИЩА АНІНІ (АЛЖИР) З МЕТОЮ ВИКОРИСТАННЯ В МЕТАЛУРГІЙНІЙ ПРОМИСЛОВОСТІ

Purpose. The study of iron ore from the Anini opencast mine aimed to develop its mineral resources for use in the metallurgical industry by ArcelorMittal Annaba (Algeria). The chemical, mineralogical and particle size analysis of representative samples showed that the studied ore is of the hematite type of clay-siliceous gangue. The preliminary enrichment was carried out based on specific properties of the iron ore.

Methodology. The characterization of the ore was carried out based on the sample analysis by means of X-ray diffractometer (XRD), reflected light optical microscope, and scanning electron microscope of type SEM 7001F. The preliminary mineral processing tests were carried out in a washing apparatus with the aim of removing the argillaceous gangue from the external surface of iron ore particles.

Findings. A grain size analysis carried out on Ro-tap screening machine with a sample of 500g crushed to 5 mm particle size showed that the release mesh of iron minerals is at about 0.5 mm. Iron content is in average > 50%. Its weight in the output makes 70% of the total mass of the sample. The tests on preliminary mineral processing by washing showed encouraging results regarding iron content and recovery.

Originality. The originality of this research consists in the application of the washing process to clean external surface of iron ore particles of the argillaceous gangue. The process suggested is inexpensive and very effective. The cost of a ton of the rich ore is low.

Practical value. Industrial application of washing method is very practical and simple-to-use. Light particles come to the top and heavy particles of iron sediment. The argillaceous gangue can be utilized in cement factories.

Keywords: *Algeria, iron ore, characterization, minerals processing, ferrous metallurgy, cement factory*

Introduction. The mining industry plays a major role in development of a gross national product of the country. Iron ore is the main raw material, 98% of this raw material is used for steel making having various areas of application and mainly in the manufacture of automobiles, in an aircraft industry and building industry [1].

Iron ore is especially rich in iron oxides, and its color changes from dark gray, luminescent-yellow, dark-violet, to rubiginous, iron contains in it for the most part in the form of magnetic iron ore (Fe_3O_4), a goethite, siderite or hematite (Fe_2O_3).

Al-Hajar complex (“Arcelor Mittal Annaba”) is the only plant in Algeria that makes steel, its productivity about one million tons per year, but it doesn't satisfy the Algerian demand for steel, that is 5 million tons. For completion of this deficiency Algeria and Qatar created the joint company in 2012 for the construction of a metallurgical complex in Bellara (Jijel) with a productivity of 5 million tons per year, this project reflects country’s commitment to the development of this branch.

In the east of Algeria, in Setif vilayet, hematite iron ore from Anini supplies industrial group of cement production of Algeria (IGCA), but its mineral composition hinder the use in metallurgical industry, in particular, because of very high content of silicon dioxide and alumina [2] that creates serious technological problems at agglomeration and the subsequent melting in a blast furnace: the high content of alumina and silicon dioxide in iron ore leads to formation of viscous slag during melting that demands the increased fuel consumption (coke) and reduces productivity [3,4].

In order to stand up to this problem connected directly with natural characteristics of mineral raw materials, hematite iron ore with dead clay and silicon rock has to be previously enriched, for improvement of its quality.

Commercially the content of alumina and silicon dioxide is reduced by means of technological processes of gravimetric sorting (hydro-cyclone); the result is the headings containing 64% of iron, 1.4% of silicon dioxide and 3.5% of alumina turns out from 57% of iron, 4% of silicon dioxide and 8.3% of alumina [4].

Sorting by means of hydro-cyclone with the subsequent magnetic separation at the high current (intensity) is used for enrichment of hematite on many India mines (Barsua, Bolani and Kiriburu) [5–7], also the process of clotting is used for content of silicon reduction of the dioxide and alumina, thus prominent results concerning percentage and recuperation [8–10] are achieved.

It is necessary to define physical and chemical, mineralogical characteristics of iron ore in order to achieve defined goals and to select mineral processing.

Materials and Methods. ***Ore sampling.*** Djebel Anini minefield is located in the karst cavities in limestones of the cenomano-turonian period; it consists of the ferriferous mix including a stony complex of loose hematite.

The sample of iron ore weighing 50 kg with the maximum diameter of 250 mm is selected on open mining on exit from primary gyratory cone breaker, the protocol of sampling is realized to prepare samples, intended for definition of physical and chemical characteristics.

Screen chemical testing of iron ore from Anini. The screen test of ore which is carried out on Rotap screen allowed defining the proportions relating to each particle-size fraction forming primary sample (fig. 1). The results obtained by means of this test (table 1) show dynamics of composition in mass percent and the content of iron in various granulometric fractions.

Table 1

Results of particle size analysis of the iron ore crushed to 5 mm

Size fractions (mm)	Mass (g)	% By mass (%)	Content of Fe_2O_3 (%)	Cumulated Refusal (%)
>4	100.86	20.17	62.01	20.17
-4+2	163.57	32.71	59.26	52.88
-2+1	86.30	17.27	51.66	70.15
-1+0.5	61.32	12.26	46.98	82.41
-0.5+0.25	41.92	8.38	46.74	90.79
-0.25+0.125	24.68	4.94	47.55	95.73
-0.125+0.063	13.26	2.65	47.02	98.38
-0,063+0.045	3.75	0.75	45.43	99.13
<0.045	4.34	0.87	45.38	100
Total	500	100		

Chemical characterization of mineral oxides from Anini. The chemical analysis by means of atomic absorption spectrophotometry was carried out on fractions, the composition in mass percent of which is prevailing; the obtain results are specified in fig. 2. In particular, excessive percentage of quartz and alumina, respectively 26.20% and 12%, is noted, it means that this type of iron ore contains mainly siliceous and clay rock. In this connection it would be interesting to enrich this type of ore for the purpose of preliminary enrichment by means of mineral processing, based on a difference of properties of minerals and rock.

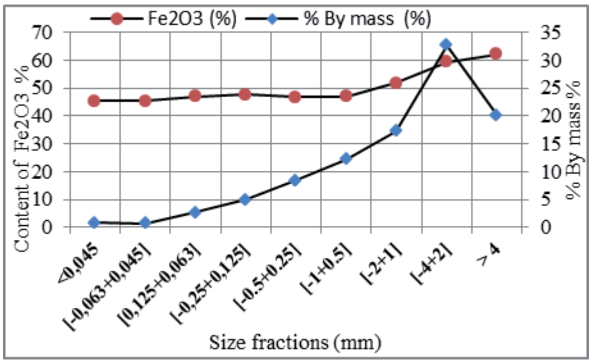

Fig. 1. Particle size analysis of Anini iron ore

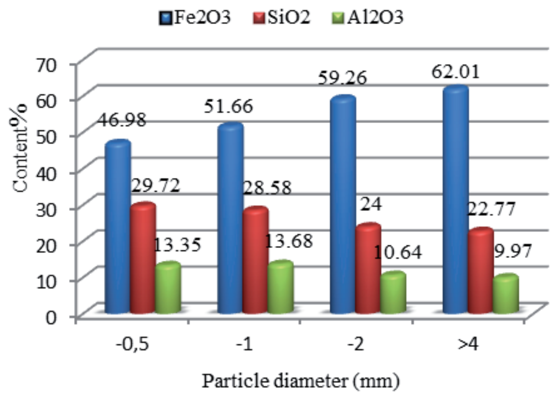

Fig. 2. Evolution of the levels of (Fe_2O_3, Al_2O_3 and SiO_2) of the studied iron ore

Self-fluxing character: basicity index. The proportions (CaO/SiO_2) or ($CaO + MgO$) / ($SiO_2 + Al_2O_3$), which are named as basicity indexes, allow to distinguish siliceous, calcareous or self-fluxing ores (table 2). Besides, according to Al_2O_3/SiO_2 proportion, classify the ore such as high-aluminous, aluminous or not aluminous ore. Ig = ($CaO + MgO$) / ($SiO_2 + Al_2O_3$), Ip = Al_2O_3 / SiO_2, Ip = CaO / SiO_2**.**

Table 2

Values of the basicity index

Fraction, mm	Global basicity index (Ig)	Partial basicity index Ip = (Al_2O_3 / SiO_2)	Partial basicity index Ip = (CaO / SiO_2)
Supply	0.06	0.47	0.06
> 4	0.06	0.43	0.05
-4 + 2	0.07	0.44	0.06
-2 + 1	0.05	0.47	0.05
<1	0.07	0.44	0.05
Average	0.06	0.45	0.05

Ore mineralogy. Ore samples subjected to supervision under an optical microscope with the reflected light, showed existence of the main following minerals:

Hematite**:** is present as knobby or band-like form with goethite, with color from white to white-gray, with weak reflective power, the mineral is anisotropic having greenish appearance (fig. 3).

Goethite**:** is different because of special colloform form, sometimes goethite has skeletal structure, grayish-white color, with rather low reflective power. In the polarized light anisotropy is pure having bluish appearance, often it is found in connection with hematite (fig. 4).

***Calcite*:** the most prevailing, it is often presented as wide range of gray color with low reflective power; this mineral is anisotropic having yellow-white appearance. Internal reflection is insignificant (fig. 5).

***Barite*:** is presented as wide range of gray color varying over chestnut with rather low reflective power, this mineral anisotropic having appearance from white to white-gray, it possesses structures with trigonous separations in the natural light (NL) (fig. 6).

The mineralogical analysis which is carried out by means of X-ray analysis (XRD) allowed to confirm the mineral composition of this ore determined by means of X-ray analysis (XRD) is specified in fig.7, it is noted an optical microscope. Results of the analysis by means of that the mineral phase observed in the majority, presented by hematite-quartz-clay with some inclusions of calcite.

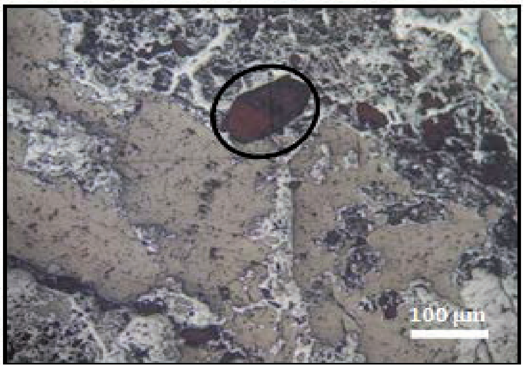

Fig. 3. Hematite surrounding a crystal Barite (NL)

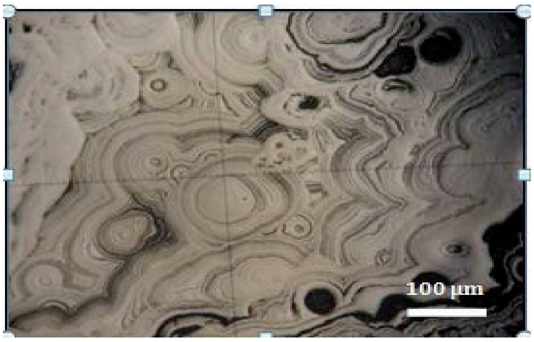

Fig. 4. Goethite of Collomorphe structure (NL)

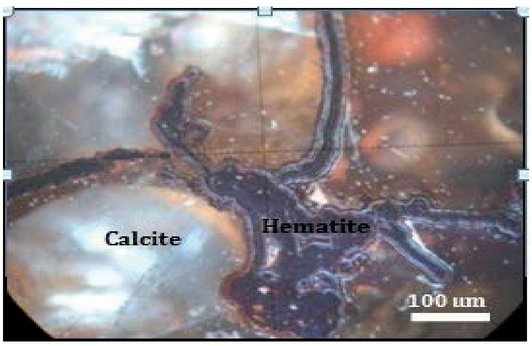

Fig. 5. Calcite associated with hematite (PL): PL – polarized light

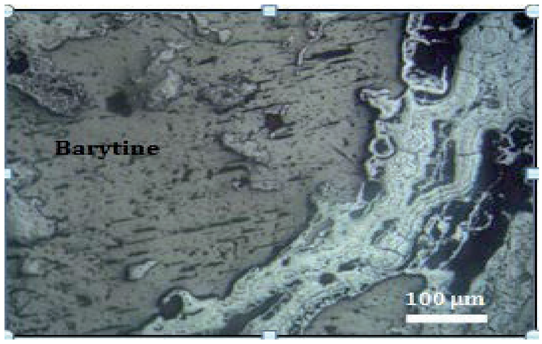

Fig. 6. Barite cracked with triangular pits (NL)

The mineralogical analysis which is carried out by means of X-ray analysis (XRD) allowed to confirm the mineral composition of this ore determined by means of X-ray analysis (XRD) is specified in fig.7, it is noted an optical microscope. Results of the analysis by means of that the mineral phase observed in the majority, presented by hematite-quartz-clay with some inclusions of calcite.

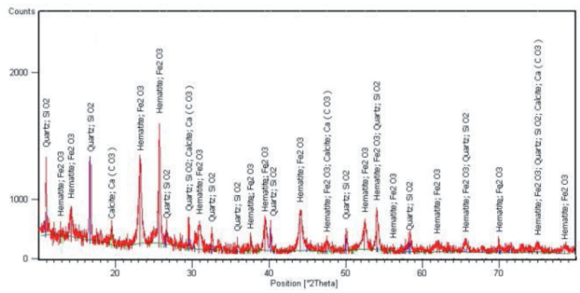

Fig. 7. Spectrum of a sample of Anini iron ore (Setif) obtained by X-ray diffractometer

The analysis by means of the scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX). There were prepared cakes with size of (2–6 mm) which were surveyed by means of the scanning electron microscope (SEM) of SEM 7001F type later. This analysis, in combination with the global chemical micro-analysis by energy-dispersive X-ray spectroscopy (EDX), allowed to determine a chemical composition of a mineral matrix of the sample [11].

There is micrography of mineral particles with a diameter about 100 µm, obtained by means of the electronic scanning microscope, represented on the fig. 8. The analysis of this sample shows that hematite is the most dominating mineral, goethite represents a minority phase, and also there are traces of calcite and quartz.

There is a sequence of the analysis, which is carried out by means of the electronic scanning microscope, the purpose of which is the exact supervision by means of SEM that shows structure in microscopic scale from the prevailing elements (O, Fe) and less numerical (Si, Al) on the fig. 9. As for oxygen, its corresponding presence is proved by that it participates in structure of Fe_2O_3, Al_2O_3, and SiO_2.

After implementation of various methods of the analysis and determination of characteristics, it has been found that the studied ore contains generally hematite iron with clay and siliceous rock, at this type of ore calcite is seldom presented. Therefore improvement of this type of ore is recommended for the purpose of compliance to strict metallurgical standards.

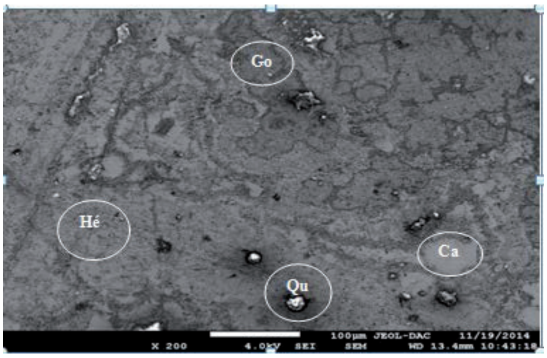

Fig. 8. Observation by scanning electron microscopy (SEM): He – Hematite; Go – goethite; Ca – calcite; Qa – quartz

Studying of preliminary enrichment of iron ore from Anini: washing (deslimation). On the basis of the obtain results of size and chemical characteristics, it has been found that the proved iron ore on average consists of 26.20% of SiO_2 and 12% of Al_2O_3. The choice of a suitable method of ore treatment depends on its use, on an industrial scale, and on the acceptable cost, taking into consideration the limiting environment conditions.

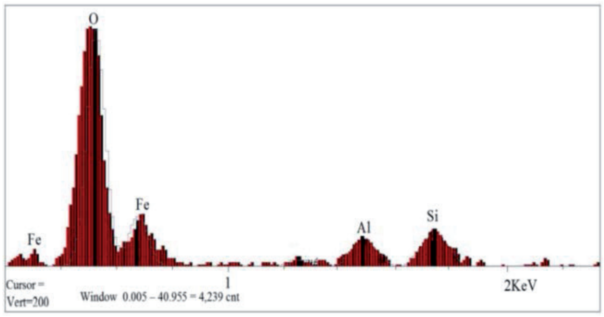

Fig. 9. X emission electron Analysis

Before purification of ore it is necessary to carry out the operation of washing (deslimation) for the purpose of removal of the pollutants and substances enveloping a surface of a mineral particle [6, 12].

The particle-size fractions prepared by means of screen separation are under tests of washing (table 3). The washed-out samples are dried up in the furnace at 105°C, and then crushed in a disk crusher; then they are investigated by means of x-ray fluorescence and atomic absorption spectroscopy.

Table 3

Wash Test Results of iron ore (200 g sample)

Fraction, mm	Refusal (g)		% By mass (%)		Passed (g)		% By mass (%)	
	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test
>4	144.50	145.60	72.25	72.80	55.50	54.40	27.75	27.20
-4+2	132.77	117.39	66.38	58.70	67.23	82.61	33.62	41.30
-2+1	111.43	109.35	55.72	54.68	88.57	90.65	44.28	45.32
<1	107.01	104.93	53.51	52.47	92.99	95.07	46.49	47.53

According to the results obtained by atomic absorption spectroscopy after washing, it makes it clear that the percentage of clay is essentially decreased, it is also noted that the content of iron in the washed-out ore is 61.57%, but not 55%.

Besides, the content of silicon dioxide in the washed-out ore decreases and varies from 26.20 to 2.30%, and content of Al_2O_3 varies from 12 to 3%. It confirms that owing to washing (deslimation) the essential results were achieved (table 4).

Table 4

Wash Test Results of Anini's iron ores

Fraction, (mm)	Samples	washing	Fe_2O_3	SiO_2	Al_2O_3	CaO	MnO	ZnO	K_2O	MgO	SO_3	CuO	Pb	P_2O_5
> 4	1	Concentrated	62.65	2.81	3.12	2.90	0 .01	0.24	0.01	0.65	0.48	0.005	0.48	0.03
		Rejected	20.57	36.89	10.22	3 .50	0.09	0.09	0.20	0.25	0.36	0.009	0.18	0.26
	2	Concentrated	61.51	2.21	3.87	2.40	0.01	0.19	0.01	0.72	0.18	0.004	0.41	0.02
		Rejected	18.19	39.56	9.98	4.96	0.02	0.11	0.21	0.28	0.26	0.010	0.17	0.28
- 4 + 2	1	Concentrated	61.28	2.01	2.86	2	0.01	0.19	0.01	0.65	0.25	0.004	0.44	0.01
		Rejected	16.71	35.86	10.33	3.79	0.10	0.13	0.19	0.21	0.46	0.008	0.18	0.34
	2	Concentrated	62.08	2.54	2.92	2.95	0.01	0.21	0.01	0.55	1.04	0.004	0.45	0.02
		Rejected	19.31	30.97	12.77	4.46	0.10	0.10	0.18	0.21	1.40	0.008	0.20	0.18
-2 + 1	1	Concentrated	61.40	2.09	3.15	2.35	0.09	0.12	0.19	0.63	0.71	0.082	0.18	0.03
		Rejected	16.03	36.81	10.12	4.29	0.10	0.12	0.18	0.21	0.34	0.008	0.17	0.22
	2	Concentrated	61.28	2.16	3.16	2.18	0.02	0.18	0.01	0.74	0.72	0.003	0.43	0.04
		Rejected	15.60	39.44	11.33	4.82	0.02	0.19	0.01	0.04	0.67	0.003	0.46	0.31
< 1	1	Concentrated	61.25	2.57	3.22	2.85	0.03	0.21	0.01	0.62	0.99	0.004	0.15	0.02
		Rejected	14.91	38.89	10.80	4.79	0.09	0.11	0.18	0,25	0.18	0.008	0.46	0.26
	2	Concentrated	61.14	2.52	2.89	2.75	0.03	0.21	0.02	0.71	0.48	0.004	0.46	0.03
		Rejected	16.74	40.56	9.98	4.79	0.09	0.08	0.18	0.21	0.34	0.004	0.16	0.28

Determination of basicity index after ore washing. The parameter of a basicity indexis absolutely essential as it expresses criterion of practicability which demands confirmation of efficiency of a method of treatment to direct ore for use in metallurgy. Proportions of lime and silicon dioxide have to be in proportion of CaO/SiO_2 which, as a rule, is from 1 to 1.5. Please, be aware that values of basicity index, indicated on table 5, are given in recommended interval.

Table 5

Values of the basicity index

Fraction (mm)	Global basicity index (Ig)	Partial basicity index Ip = (Al_2O_3 / SiO_2)	Partial basicity index Ip = (CaO / SiO_2)
> 4	1.11	1.43	1.05
- 4 + 2	0.58	1.28	1.08
- 2 + 1	0.55	1.48	1.06
<1	0.61	1.39	1.10
Average	0.71	1.39	1.07

Deslimation Efficiency of ore study. Comparison of results of the chemical analyses obtained after application of this method is decisive. In the retained material after operation of washing (fig.10, 11) the increase of iron content to 62%, and also essential decrease of silicon dioxide content about 2.36% and alumina content which is 3.33% are observed. The analyses of results provided in fig. 12, 13 show high percentages of the silicon dioxide and alumina (37.37 and 10.69%) in a screen underflow after screening.

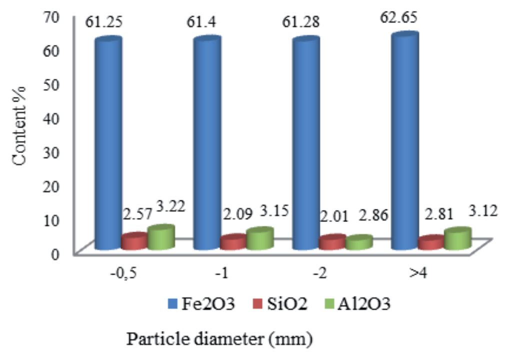

Fig. 10. Contents evolution of (Fe_2O_3, SiO_2 and Al_2O_3) in the sample washed with water (concentrate) of Test n° 1

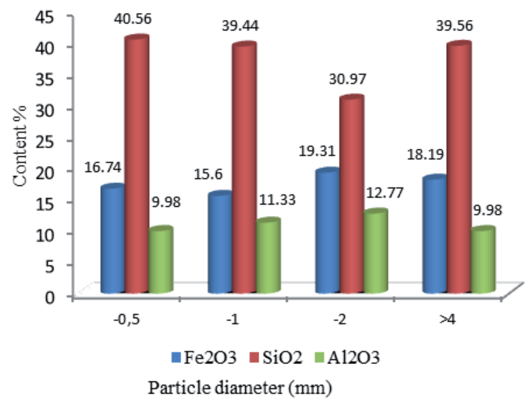

Fig. 11. Contents evolution of (Fe_2O_3, SiO_2 and Al_2O_3) in the sample washed with water (rejected) of Test n° 2

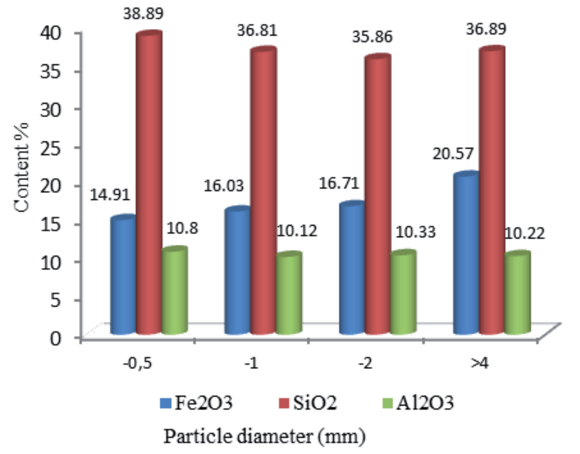

Fig. 12. Contents evolution of the (Fe_2O_3, SiO_2 and Al_2O_3) in the sample washed with water (rejected) of Test n° 1

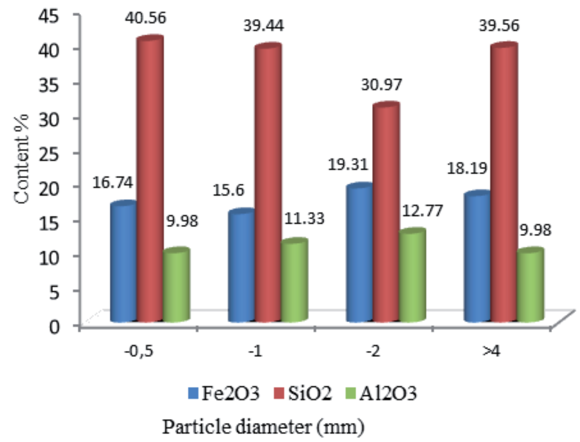

Fig. 13. Contents evolution of (Fe_2O_3, SiO_2 and Al_2O_3) in the sample washed with water (rejected) of Test n° 2

The results of refraction of X-rays relating to the retained material and screenings after operation of washing (fig. 14,15) show that the rich retained material (concentrate) mainly consists of the hematite containing inclusions of germanium (Ge), the last one combines with barium in consequence of which we have ore with a valuable chemical composition (Ba, Mg) Ge_2O_6, whereas in screenings (rejection) there is a prevalence of the quartz containing a small proportionate share of hematite.

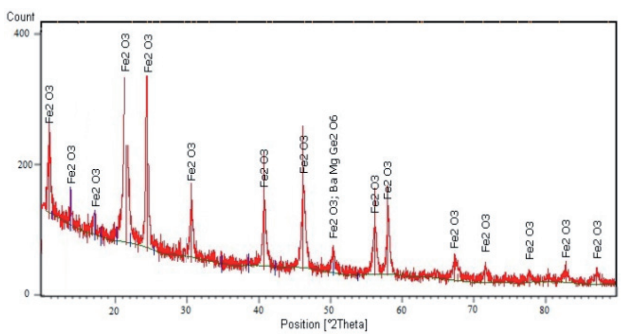

Fig. 14. Sample spectrum of the concentrate obtained after washing

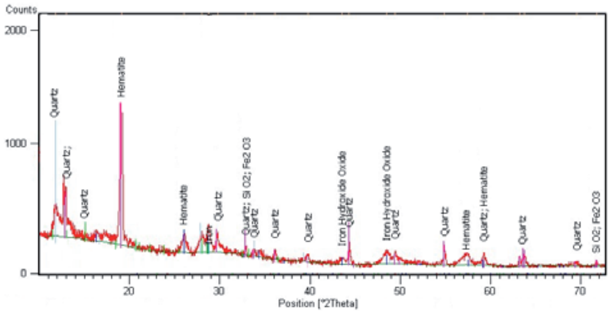

Fig. 15. Spectrum of a washed sample (rejected)

The results obtained in the time of carrying out preliminary tests on enrichment allowed achieving the research goals for use in metallurgical industry at the minimum cost, it is noted that such project can be realized on iron mine of Anini, and by-products of this process can be used by cements production. The scheme of preparation and enrichment of ore is represented in fig. 16.

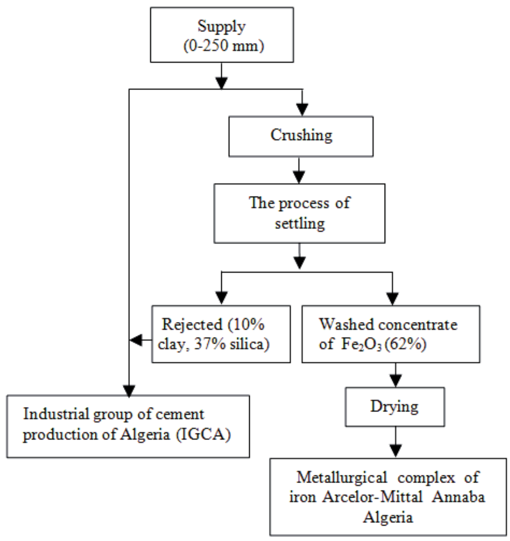

Fig. 16. Diagram of the proposed preparation for the enrichment of Anini's iron ore

Conclusion. Research of mineral processing process demands preliminary determination of physical and chemical properties of ore, for the best understanding of aspects of natural characteristics of raw materials:

- in case of the research conducted concerning iron ore of Anini it makes clear that the last one contains mainly ferriferous hematite rocks with inclusions of quartz and clay;
- the screen chemical analysis of samples shows that the material balance of iron ore is encouraging (efficiency, the content of iron), the average content of iron is 55%, on the other side, percentage of SiO_2 and Al_2O_3 also very remarkable and reaches respectively 26.20 and 12% ;
- the mineralogical analysis by means of XRD confirms that the prevailing observed mineral phase is hematite – quartz – clay and some inclusions of calcite in this matrix;
- according to the tests which are carried out for this type of ore, it has transpired that the last one can be a subject of preliminary enrichment by means of washing (desliming), it is noted that the reached content of iron is 62% in comparison with 55% in not washed out ore (as-mined ore); besides, the maintenance of SiO_2 and Al_2O_3 in the washed-out ore decreases from 26.20 to 2.30% of SiO_2 and from 12 to 3% of Al_2O_3;
- the calculated partial basicity index [Ip= (CaO/SiO_2)] averages 1.07, that shows that the washed-out ore conforms to use standards in metallurgy;
- the by-products remaining after washing (quartz, clay and the small content of iron) can be used in cement production.

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Мета. Дослідження залізної руди, що видобувається в кар'єрі „Аніні", спрямоване на розвиток мінеральних ресурсів родовища для використання в металургійній промисловості підприємством „Арселор Міттал Аннаба", Алжир. Хімічний, гранулометричний і мінералогічний аналіз проб показує, що досліджувана руда відноситься до гематитового типу й міститься у глинистих і кременистих жильних породах. Її попереднє збагачення здійснюється, виходячи з питомих властивостей цих залізних руд.

Методика. Визначення характеристик руди здійснювалося наступними методами аналізу проб: рентгеноструктурний (рентгенодифракційний) аналіз (XRD), спостереження під дзеркальним оптичним мікроскопом і растровим електронним мікроскопом (РЕМ) моделі SEM 7001F. Досліди з попереднього збагачення були проведені у промивальному пристрої з метою видалення глинистих породних домішок з поверхні залізної руди.

Результати. Гранулометричний аналіз проби вагою в 500 г, подрібненої до частинок розміром 5 мм, був проведений на просіювальній машині Ro-tap. Результати показали, що розмір отворів сита для відділення частинок заліза становить близько 0,5 мм. Середній вміст заліза перевищує 50% і складає на виході 70% від загальної маси проби. Досліди з попереднього збагачення способом промивання показали обнадійливі результати стосовно вмісту та відновлення заліза.

Наукова новизна. Спосіб промивки був застосований для видалення глинистих породних домішок з поверхні гранул залізної руди. Запропонований спосіб є недорогим і дуже ефективним. Високий вміст заліза досягається за низької собівартості обробленої тонни руди.

Практична значимість. Промислове застосування процесу збагачення за допомогою промивання відрізняється практичністю та простотою виконання. Легкі частинки домішок спливають на поверхню води, у той час як важкі частинки заліза осаджуються. Відокремлена глиниста порода придатна до використання на цементних заводах.

Ключові слова: *Алжир, залізна руда, визначення характеристик руди, збагачення, чорна металургія, цементний завод*

Цель. Исследование железной руды, добываемой в карьере „Анини", направлено на развитие минеральных ресурсов месторождения для использования в металлургической промышленности предприятием „Арселор Миттал Аннаба", Алжир. Химический, гранулометрический и минералогический анализ проб показывает, что исследуемая руда относится к гематитовому типу и содержится в глинистых и кремнистых жильных породах. Её предварительное обогащение осуществляется, исходя из удельных свойств этих железных руд.

Методика. Определение характеристик руды осуществлялось следующими методами анализа проб: рентгеноструктурный (рентгенодифракционный) анализ (XRD), наблюдение под зеркальным оптическим микроскопом и растровым электронным микроскопом (РЭМ) модели SEM 7001F. Опыты по предварительному обогащению были проведены в промывочном устройстве с целью удаления глинистых породных примесей с поверхности железной руды.

Результаты. Гранулометрический анализ пробы весом в 500 г, измельчённой до крупности 5 мм, был проведен на просеивающей машине Ro-tap. Результаты показали, что размер ячеек сита для отделения частиц железа составляет около 0,5 мм. Среднее содержание железа превышает 50% и составляет на выходе 70% от общей массы пробы. Опыты по предварительному обогащению способом промывки показали обнадеживающие результаты касательно содержания и восстановления железа.

Научная новизна. Способ промывки был применен для удаления глинистых породных примесей с поверхности гранул железной руды. Предложенный способ является недорогим и очень эффективным. Высокое содержание железа достигается при низкой себестоимости обработанной тонны руды.

Практическая значимость. Промышленное применение процесса обогащения с помощью промывки отличается практичностью и простотой осуществления. Легкие частицы примесей всплывают на поверхность воды, в то время как тяжелые частицы железа осаждаются. Отделенная глинистая порода пригодна к использованию на цементных заводах.

Ключевые слова: *Алжир, железная руда, определение характеристик руды, обогащение, черная металлургия, цементный завод*

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