Mining Science, vol. 22, 2015, 201−213

www.miningscience.pwr.edu.pl

Mining Science
(previously Scientific Papers of the Institute of Mining of the Wroclaw University of Technology. Mining and Geology)

ISSN 2300-9586
previously 0370-0798

Received: March 17, 2015; reviewed; accepted September 19, 2015

A PRELIMINARY STUDY ON ENRICHMENT OF ANINI IRON ORE FOR USE BY ALGERIAN METALLURGICAL INDUSTRY

Raouf CHAABIA*, Mohamed BOUNOUALA, Mohamed Laid BOUKELLOUL

Department of Mining, Faculty Earth Sciences, Badji Mokhtar-Annaba University,Annaba, Algeria

Abstract : The Anini iron ore contains mainly ferriferous hematite rocks with inclusions of quartz and clay. The chemical analysis showed that the average content of iron is 55% while SiO_2 and Al_2O_3 is 26.20% and 12%, respectively. The XRD mineralogical analysis confirmed that the prevailing mineral phase are hematite, quartz, clay and some inclusions of calcite in this matrix. According to the tests, preliminary desliming by washing provides iron 62% is the concentrate while SiO2 decreases from 26.20% to 2.30% and Al2O3from 12% to 3%. The calculated partial basicity index Ip= (CaO/SiO2) was 1.07, meaning that the washed-out ore achieves standards to be used in metallurgy. The by-products remaining after washing (quartz, clay and a small content of iron) can be used in cement production.

Keywords: enrichment, iron ore, desliming, basicity index, metallurgy

INTRODUCTION

The mining industry plays a major role in development of a gross national product of any country. Iron ore is an important raw material. Almost 98% of this raw material is used for steelmaking having various areas of application including manufacture of automobiles, aircraft and building industry (Olivier, 2012). Iron ore is rich in iron oxides. Its color varies from dark gray, luminescent-yellow, dark-violet, to rubiginous. Iron is present mostly as magnetite (Fe_3O_4), goethite, siderite and hematite (Fe_2O_3).

The Al-Hajar complex (Arcelor Mittal Annaba) is the only plant in Algeria that makes steel. Its productivity is about one million tons per year, but it doesn't satisfy

---

* Corresponding author: chaabiaraouf@gmail.com (R. Chaabia)

doi: 10.5277/msc152217

Algeria's demand for steel which is 5 million tons. In order to complement this deficiency, Algeria and Qatar created a 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 the countries' commitment to the development of this branch. In the east of Algeria, in the Setif vilayet, hematite iron ore from Anini supplies industrial group of cement production of Algeria (IGCA), but its mineral composition hinders its use in metallurgical industry, in particular because of very high content of silicon dioxide and alumina (Ghamoud, 2009). That creates serious technological problems with agglomeration and subsequent melting in a blast furnace. The high content of alumina and silicon dioxide in the iron ore leads to formation of viscous slag during melting that demands an increased fuel consumption (coke) and reduces productivity (Upadhyay and Venkatesh, 2006; Subrata, 2009). In order to address the problem connected directly with natural characteristics of mineral raw materials, hematite iron ore with clay and silicon rock has to be previously enriched, which will result in improvement of its quality.

Commercially, the content of alumina and silicon dioxide is reduced by means of technological processes of gravimetric sorting (hydrocyclones). The result is the concentrate containing 64% of iron, 1.4% of silicon dioxide and 3.5% of alumina made out of 57% of iron, 4% of silicon dioxide and 8.3% of alumina (Subrata, 2009).

Sorting by means of hydrocyclones with the subsequent magnetic separation at high current intensity is used for enrichment of hematite in many mines of India (Barsua, Bolani and Kiriburu iron ore washing plants) (Das et al., 1995; Mohanty and Das, 2010; Jena et al., 2015). Also the process of clotting is used for reduction of the content of silicon dioxide and alumina. Thus, prominent results concerning percentage and recuperation (Gujraj et al., 1983; Mahiuddin et al., 1989; Drzymala and Fuerstenau, 2014) are achieved. It is necessary to define physical, chemical and mineralogical characteristics of iron ore in order to achieve defined goals and to select mineral processing.

MATERIALS AND METHODS

MATERIALS

The Djebel Anini field is located in the karst cavities in limestones of the cenomano-turonian period. It consists of a ferriferous mix including a stony complex of loose hematite. The sample of iron ore, weighing 50 kg with the maximum diameter of lumps about 250 mm was selected from an open mining pit at the exit from the 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 was carried out on a Rotap screen allowed to define the size distribution of the primary sample. The results shown in Table 1 present size 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		

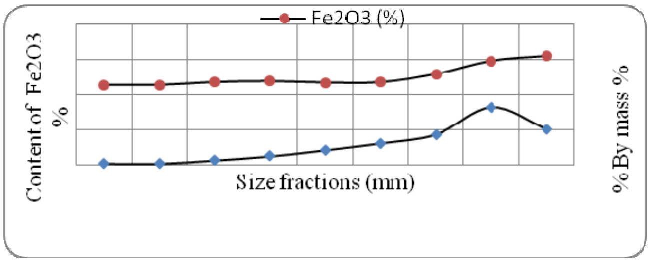

Fig. 1. Particle size analysis of Anini iron ore

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, is shown in Figure 2. 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. Therefore, it would be interesting to enrich this type of ore for the purpose of preliminary enrichment by means of mineral processing, based on different properties of minerals in the rock.

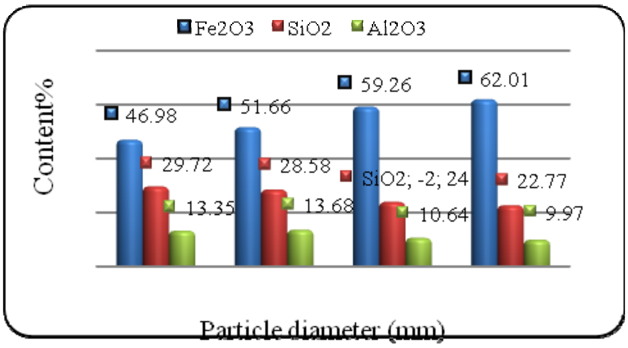

Fig. 2. Evolution of Fe_2O_3, Al_2O_3 and SiO_2 content in the studied iron ore

SELF-FLUXING CHARACTER. BASICITY INDEX

The proportion (CaO/SiO_2) or ($CaO + MgO$) / ($SiO_2 + Al_2O_3$), which are referred to as basicity indexes, allow to distinguish siliceous, calcareous or self-fluxing ores. Besides, according to Al_2O_3/SiO_2 proportion, we can classify the ore as high-aluminous, aluminous or not aluminous ore. The indices are:

$$Ig = (CaO + MgO) / (SiO_2 + Al_2O_3),\ Ip = Al_2O_3 / SiO_2,\ Ip = CaO / SiO_2$$

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

The samples observed under an optical microscope with reflected light showed existence of hematite, goethite, calcite and barite. Hematite is present as a knobby or band-like form with goethite, with colors from white to white-gray, with weak reflective power. The mineral is anisotropic having greenish appearance (Fig. 3). Goethite is different because of special form. Sometimes goethite has a skeletal structure, grayish-white color, with rather low reflective power. In the polarized light, anisotropy is pure having bluish appearance. It is often found together with hematite (Fig. 4). Calcite is prevailing. It is often presented in a wide range of gray color with low reflective power. This mineral is anisotropic having yellow-white appearance. Internal reflections are insignificant (Fig. 5). Barite is presented in a wide range of gray color with rather low reflective power. This mineral is anisotropic having appearance from white to white-gray. It possesses structures containing trigonous separations in the natural light (NL) (Fig. 6).

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

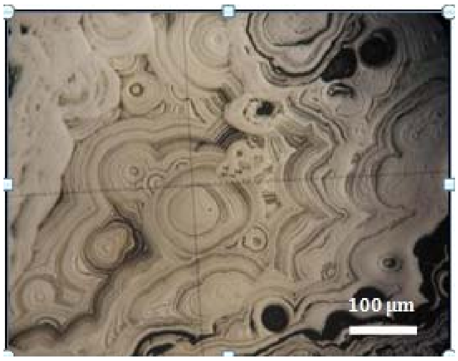

Fig. 4. Goethite of a collomorphe structure (NL)

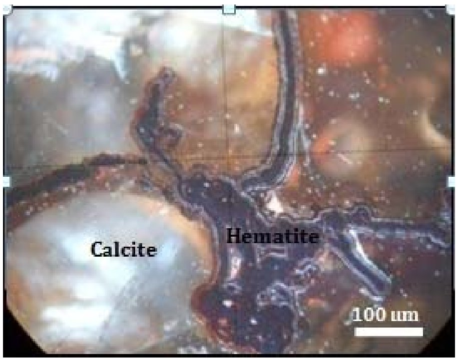

Fig. 5. Calcite associated with hematite (PL)

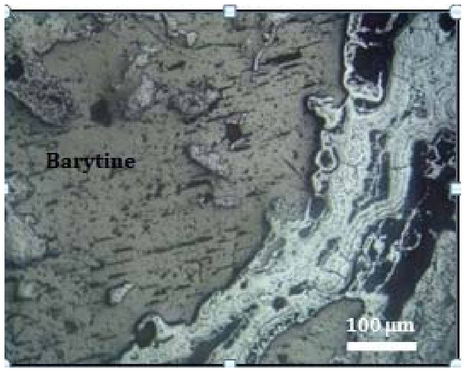

Fig. 6. Barite cracked with triangular pits (NL)

The mineralogical analysis carried out by means of X-ray analysis (XRD) confirmed the mineral composition of the ore determined by means of the optical microscope. The results of the analysis made by means of X-ray analysis (XRD) are specified in Figure 7. I should be noted that the major mineral phase was hematite-quartz-clay with some inclusions of calcite.

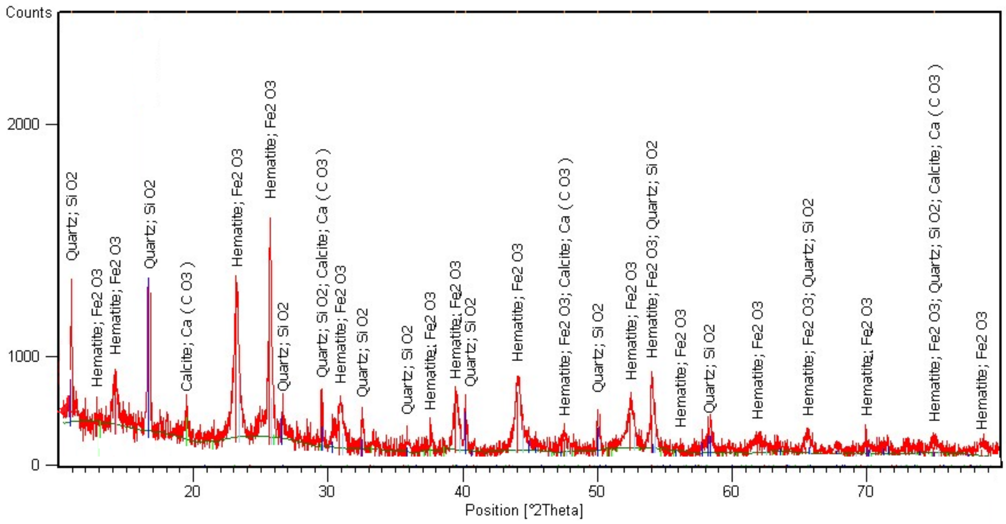

Fig. 7. Spectrum of a sample of Anini iron ore (Setif) obtained by an X-ray diffractometer

ANALYSIS BY MEANS OF SCANNING ELECTRON MICROSCOPE (SEM) AND ENERGY-DISPERSIVE X-RAY SPECTROSCOPY (EDX)

The prepared sample (2–6 mm in size) was subsequently surveyed by means of a scanning electron microscope (SEM 7001F). This analysis, in combination with a global chemical microanalysis by an energy-dispersive X-ray spectroscopy (EDX), allowed for determining the chemical composition of a mineral matrix of the sample (Mouna, 2011).

A micrography of mineral particles about 100 µm in size, obtained by means of an electronic scanning microscope, is presented in Fig. 8. It shows that hematite is the dominating mineral, goethite represents a minority phase, and there are also traces of calcite and quartz.

The results of analysis carried out by means of the electron scanning microscope, whose purpose was to check the XRD data, show the prevailing elements (O, Fe) to less significant (Si, Al) (Fig. 9). As for oxygen, it is present in Fe_2O_3, Al_2O_3, and SiO_2.

The data show that the studied ore contains generally hematite with clay and siliceous rock. In this type of ore, calcite is seldom present. Therefore, the upgrading of this type of ore is recommended for the purpose of compliance with strict metallurgical standards.

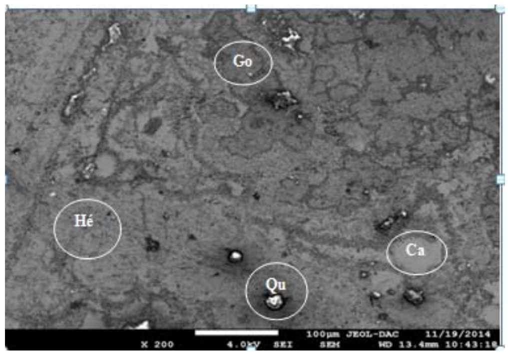

Fig. 8. Observation through scanning electron microscopy (SEM)
He: Hematite, Go: goethite, Ca: calcite, Qa: quartz

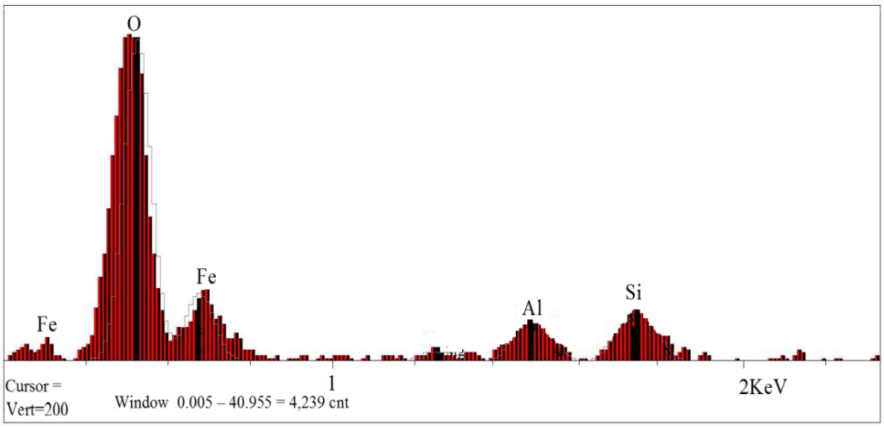

Fig. 9. X emission electron scanning microscope analysis

STUDY OF PRELIMINARY ENRICHMENT OF IRON ORE FROM ANINI. WASHING (DESLIMATION)

On the basis of the obtained results of size and chemical characteristics, it has been found that the 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 environmental limitations. Before purification of ore, it is necessary to carry out operation of washing (deslimation) for the purpose of removal of pollutants and substances enveloping the surface of a mineral particle (Maryam et al., 2014; Jena et al., 2015).

The particle size fractions, prepared by means of screening after washing are given (Tab. 3). The washed-out samples were dried up in the furnace at 105 °C, and then crushed in a disk crusher. Subsequently, they were 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 becomes apparent that percentage of clay essentially decreased. It was also noted that the content of iron in the washed-out ore is 61.57%, 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 proves that the essential results were achieved through washing (deslimation).

Table 4. Wash test results of Anini 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 basicity index is absolutely essential as it expresses the criterion of practicability which demands confirmation of efficiency of a method of treatment to prepare the ore for use in metallurgy. Proportions of lime and silicon dioxide as a rule varies from 1 to 1.5. It should be noted that values of basicity index, shown in Table 4, are given in recommended intervals.

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 THE STUDIED ORE

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

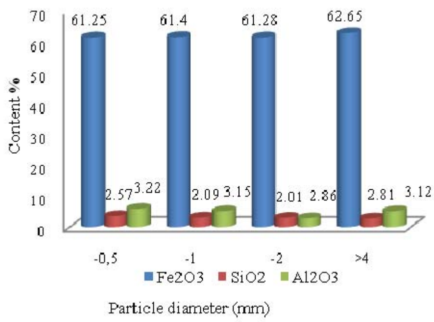

Fig. 10. Content evolution of Fe_2O_3, SiO_2 and Al_2O_3 in the sample washed with water (concentrate) of Test n° 1.

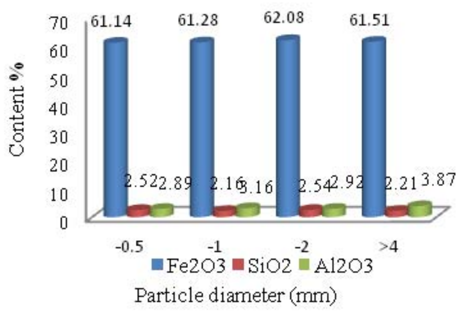

Fig. 11. Content evolution of Fe_2O_3, SiO_2 and Al_2O_3 in the sample washed with water (concentrate) of Test n° 2.

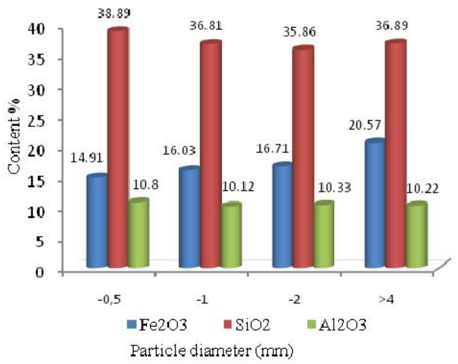

Fig. 12. Content evolution of Fe_2O_3, SiO_2 and Al_2O_3 in the sample washed with water (rejected) of Test n° 1.

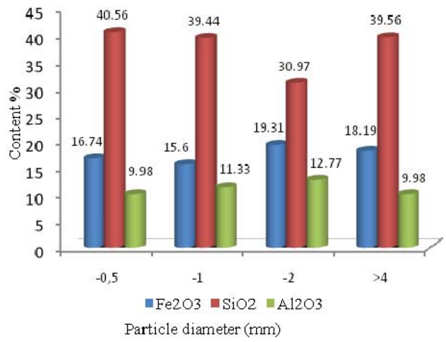

Fig. 13. Contents evolution of Fe_2O_3, SiO_2 and Al_2O_3 in the sample washed with water (rejected) of Test n° 2.

X-rays results for concentrate and reject (Fig. 14 and 15) show that concentrate mainly consists of the hematite containing inclusions of germanium combined with barium (Ba, Mg) Ge_2O_6, whereas in reject there is a prevalence of quartz containing a small amount of hematite.

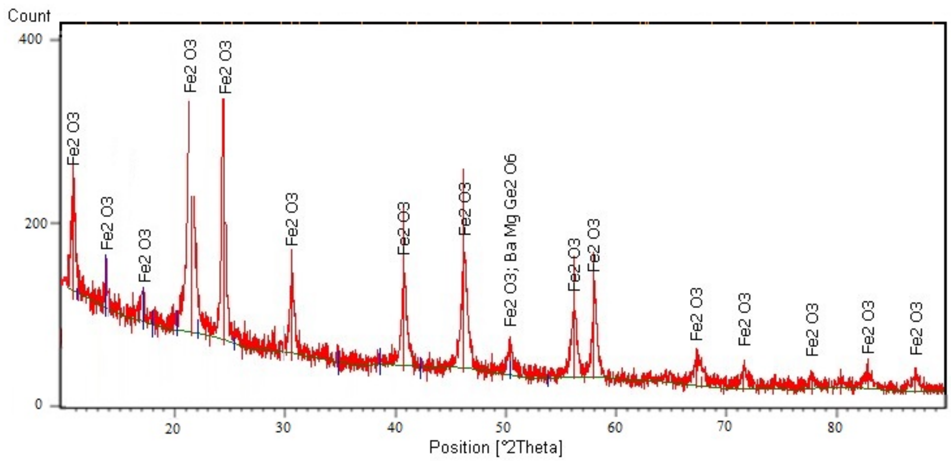

Fig. 14. Sample spectrum of concentrate obtained after washing

Results obtained in preliminary enrichment tests allowed for achieving the research goals related to its use in metallurgical industry at the minimum cost. It should be noted that such project can be realized in the iron mine of Anini. The by-products of this process can be used in production of cement. The preparation and enrichment of ore chart is presented in Fig. 16.

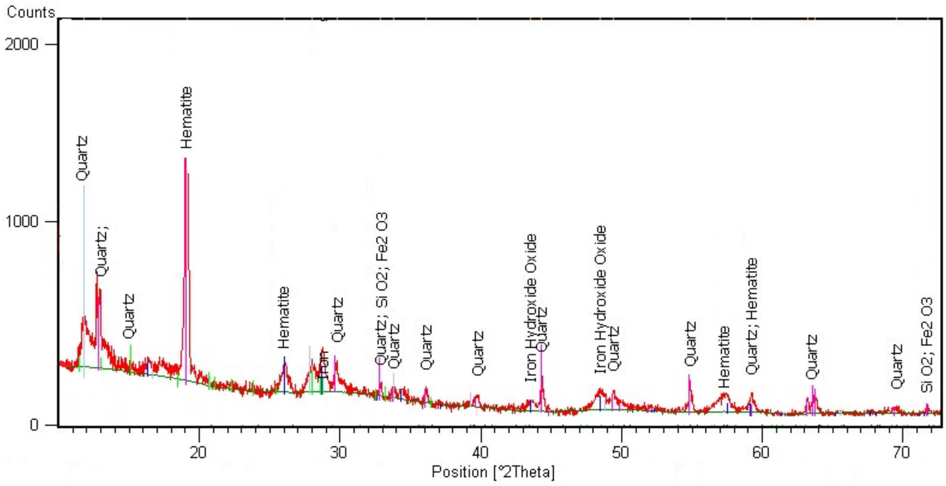

Fig. 15. Spectrum of washing reject

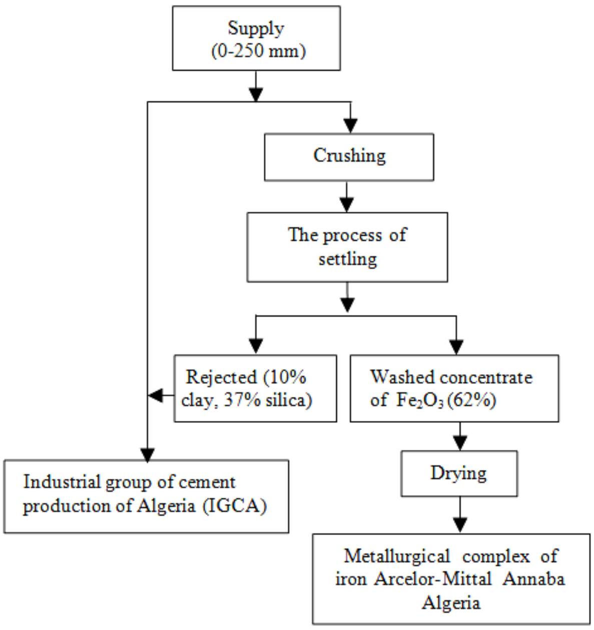

Fig. 16. Diagram of the proposed enrichment of Anini iron ore

CONCLUSION

Research on processing of an ore requires a preliminary determination of physical and chemical properties of the ore. In the case of the Anini iron ore, it became clear that the it contains mainly ferriferous hematite rocks with inclusions of quartz and clay. The screening fractions chemical analysis showed that the material balance of iron ore is encouraging (efficiency, content of iron) because the average content of iron is 55%. On the other hand, the percentage of SiO_2 and Al_2O_3 is high and reaches respectively 26.20% and 12%. The mineralogical analysis by means of XRD confirms that the prevailing mineral phase is hematite – quartz – clay and some inclusions of calcite in this matrix. According to the tests, which were carried out for the ore, an enrichment by means of washing (deslimation) provides iron of 62% in comparison with 55% in the unwashed ore (as-mined ore). Besides, the SiO_2 and Al_2O_3 content in the washed-out ore decreases from 26.20% to 2.30% for SiO_2 and from 12% to 3% for Al_2O_3. The calculated basicity index [Ip = (CaO/SiO_2)] was on average 1.07. This shows that the washed-out ore conforms to standards of use in metallurgy. The by-products remaining after washing (quartz, clay and the small content of iron) can be used in the cement production.

REFERENCES

DAS B., MOHAPATRA B. K., REDDY P. S. R., DAS, S., 1995. *Characterization and beneficiation of iron ore slimes for further processing*, Powder Handling and Process, 7(1), 41–44.

GHAMOUD, K., 2009. *Audit environnemental de la carrière de djebel Anini "FERPHOS",* Bureau d'Etudes Géologiques & Minières, Rapport inédit, 51.

GUJRAJ B., SHARMA J. P., BALDAWA A., ARORA S. C. D., PRASAD N., BISWAS A. K., 1983. *Dispersion-flocculation studies on hematite-clay systems,* International Journal of Mineral Processing, vol, 11, 285–302.

DRZYMALA J.,FUERSTENAU D. W., 2014. *Selective flocculation of hematite in quartz–hematite–ferricion–polyacrylic acid system, Part 2, Effect of grinding and a hydrofluoric treatment on selectivity of flocculation*, International Journal of Mineral Processing, vol. 129, –5.

JENA S. K., SAHOO H., RATH S. S., RAO D. S., DAS S. K., DAS B., 2015. *Characterization and Processing of Iron Ore Slimes for Recovery of Iron Values*, Mineral Processing and Extractive Metallurgy Review, 36:3, 174–182.

MAHIUDDIN S., BANDOPADHYAY S., BARUAH J. N., 1989. *A study on the beneficiation of Indian iron ore fines and slime using chemical additives*, International Journal of Mineral Processing, vol, 11, 285–302.

MARYAM S., CLAUDE B., MARILÈNE R., 2014. *Effect of wash water on the mineral size recovery curves in a spiral concentrator used for iron ore processing*, International Journal of Mineral Processing, 129, 22–26.

MOHANTY S. and DAS B., 2010. *Optimization studies of hydrocyclone for beneficiation of iron ore slimes,* Mineral Processing & Extractive Metall. Rev., 31:2, 86–96.

MOUNA C., 2011. *Synthèse de gels phosphocalciques issus de déchets industriels carbonatés Caractérisation physico-chimique, thermique et rhéologique*, Thèse de doctorat, université de Toulouse, 170.

OLIVIER D., 2012. *Minerai de fer, l'émergence d'une nouvelle commodité sur les marchés financiers*, Haute École de Gestion de Genève (HEG-GE), 57.

SUBRATA R., 2009. *Recovery improvement of fine iron ore particles by multi gravity separation*, The Open Mineral Processing Journal, 2, 17–30.

UPADHYAY R.K. and VENKATESH A.S., 2006. *Current strategies and future challenges on exploration, beneficiation and value addition of iron ore resources with special emphasis on iron ores from eastern India*, Applied Earth Science IMM Transactions Section B, vol, 115, 187–195.