https://doi.org/10.31713/m1003

POSSIBILITIES TO RECOVER ALUMINUM FROM MINING WASTE DUMPS LOCATED IN JIU VALLEY. ECONOMIC, SOCIAL AND ENVIRONMENTAL OPPORTUNITIES

Faur F.
University of Petroşani, Faculty of Mining, Department of Environmental Engineering and Geology, Doctor of Engineering Sciences, Lecturer, Romania

Lazăr M.
University of Petroşani, Faculty of Mining, Department of Environmental Engineering and Geology, Doctor Habil. of Engineering Sciences, Professor, Vice-Rector for Scientific Research and International Relations, Romania

Apostu I.-M.
University of Petroşani, Faculty of Mining, Department of Environmental Engineering and Geology, Doctor of Engineering Sciences, Assistant Professor, Romania

Rada C.
University of Petroşani, Faculty of Mining, Department of Environmental Engineering and Geology, PhD Student of Engineering Sciences, Romania

Abstract

The exploitation of low-grade ore deposits or the recovery of useful minerals from old waste dumps and tailing ponds is considered as an interesting economic opportunity especially in the context in which we speak more and more of a reduction in availability of some mineral resources or depletion of conventional ore deposits. The exploitation of old waste dumps and tailing ponds is possible on the one hand due to progress in terms of processing technologies (process efficiency and by lowering the minimum useful content that can be recovered) and on the other by the rise in the demand and the price on the internal and international markets for some useful mineral substances.

This paper presents some considerations related to the opportunity to extract useful mineral substances, more precisely aluminum, contained in coal mining waste dumps from Jiu Valley (Romania), regarded in terms of economic, social and environmental benefits.

Keywords: waste dumps, bauxite, aluminum, sterile rocks, Jiu Valley

Introduction

The history of the southern part of Hunedoara County (Romania), known as the Jiu Valley, is definitely linked to the discovery and exploitation of coal deposits (hard coal) [9].

An inevitable consequence of coal mining and pro is the appearance of mining waste dumps (about 60 scattered along the Jiu Valley) in which important quantities of rocks, of different types (sandstones, marls, clays, etc.) are stored and which occupy appreciable areas of land [12]. Of course, in the 21st century these engineering structures are seen as environmental problems that must be solved in one way or another by mining operators.

Thus, in line with the objectives of modern mining, the operators and investors have begun to view these rock deposits not only as environmental issues, but also as possible sources of useful minerals, other than those originally mined in the area.

Although the chemical analyzes that demonstrate the presence of this element (aluminum) in a concentration that allows taking into account the possibility of recovery were performed on material from only two of the four active waste dumps, judging from their location (inside Petroşani mining basin) and similar geological conditions (including those related to the genesis of the carbonaceous deposit), it can be extrapolated that the material from the other two waste dumps is similar in terms of the aluminum content [8].

In this context, the present paper analyzes the opportunity to extract the aluminum ore (bauxite) (figure 1) contained in the four active coal mining waste dumps from Jiu Valley and further needed processing operations in order to obtain a salable product (99.7 % pure aluminum).

a *b*

Fig. 1. Bauxite fragment (with calcite depositions) collected from Lonea I waste dump: *a* – front view; *b* – side view)

Given the presented aspects, the assessment of the total amount of aluminum that can be recovered and its economic value refers to the total volume of the bauxite stored in the four active waste dumps from Jiu Valley.

The origin of the material from sterile deposits

Due to productive activities conducted in the four mines that are sill operating in Jiu Valley (Lonea, Livezeni, Vulcan and Lupeni), results a relatively large amount of sterile rocks that are stored in four waste dumps located in valleys or on slopes (figure 2).

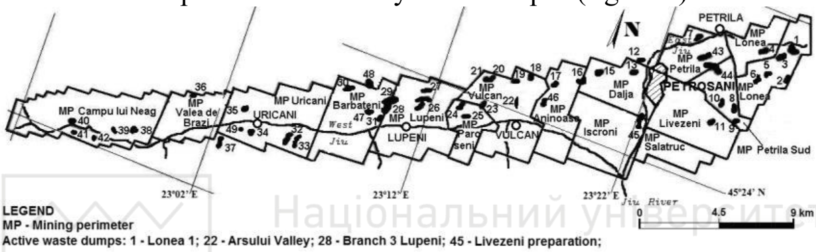

Fig. 2. Location of active waste dumps from Jiu Valley [13]

The mining mass from the dumps is composed of a heterogeneous mixture of soft rocks (such as clay or marls) and hard rocks (such as sandstones) with a pronounced unevenness of granulometry and physical and mechanical properties (figure 3*a*-*d*) [12].

a *b*

c d

Fig. 3. Details regarding the stored material: *a* – Lupeni; *b* - Arsului Valley;

c - Livezeni and *d* – Lonea waste dumps

Since the four dumps are located in valleys and on inclined terrains, for their construction there were used conveyor systems (Lonea and Livezeni), dumping trucks (Vulcan) and funicular installations (Lupeni). Through them it was ensured the transport and deposition of the sterile rocks in the waste dumps. The dumps were constructed on different alignments and the discharge points were determined according to the configuration of the terrain on the respective alignments.

Description of the active waste dumps

In order to increase storage capacity, the material discharged from the transportation systems is generally pushed laterally by bulldozers, forming deposition platforms. The platforms width varies between 15 and 50 m at the top and between 50 and 150 m at the bottom (at the contact with the base natural terrain) [12, 13].

Dumps height varies between 3 and 4 m (in the contact areas with the inclined base terrains) and between 30 and 40 m (where the material is deposited on horizontal terrains). The slope angle, in situations where plastics leakage occurred has values of 7-8 degrees, but generally it is between 40 and 50 degrees [12, 13]. During the discharge or when the waste material is pushed by bulldozers a particle size-sorting takes place, the coarse material is deposited at the base of the dumps and, also, there is a tendency for the material to arrange itself at slope angles greater than the final one. If the base terrain has abrupt slopes, the flattening of the waste dumps slopes is more obvious and the material requires more space to expand.

At present there are four active waste dumps, belonging to the four underground mines that are currently in operation. However two of them (those belonging to Lonea and Lupeni mines) will soon be put into conservation. The other two (belonging to Livezeni and Vulcan mines) will be in operation at least until 2024. Although the waste dumps are considered to be stable or relatively stable, the isolated instability incidents involving these artificial engineering constructions exert a negative influence on the immediately surrounding terrains [13].

The total area of terrains occupied by the four waste dumps exceeds 14 ha and the volume of waste material stored is over 2.7 million m^3 (table 1).

Table 1

Active mining waste dumps from Jiu Valley

Waste dump	Mining Unit	Dump surface [m^2]	Designed capacity [m^3]	Used capacity [m^3]
Branch 3 Lupeni	Lupeni ME	62,700	2,000,000	1,360,108
Arsului Valley	Vulcan ME	17,500	1,200,000	367,918
Livezeni preparation	Livezeni ME	37,500	800,000	563,619
Lonea 1	Lonea ME	23,000	4,000,000	426,119
TOTAL	-	140,700	8,000,000	2,717,764

ME – mining exploitation

The laboratory analysis carried out over the years, regarding the physical characteristics of the dumped material, shows that the average volumetric density is of 1,820 kg/m^3 [13], which means that in the four active waste dumps the total stored quantity of sterile is of approx. 4,95 million *t*.

Chemical analysis of the waste rocks

To determine the chemical composition of the deposited material, samples were collected from two dumps (Lonea I waste dump – located in the eastern edge of Petroşani coal basin and Arsului Valley Vulcan waste dump - located in the center of the basin) and subjected to laboratory analysis using a S4 Pioneer spectrometer. The results of these tests are shown in table 2.

Table 2

Chemical composition of the waste material [7, 8]

No.	Parameter	Measuring unit	Determined value	
			Lonea I (Lonea ME)	Arsului Valley (Vulcan ME)
1	Volatile	%	69.60	60.00
2	Si	%	22.40	22.30
3	**Al**	**%**	**9.82**	**10.70**
4	Fe	%	3.04	2.37
5	K	%	2.33	2.20
6	Ca	%	0.69	0.52
7	Ti	%	0.60	0.51
8	Na	%	0.49	0.49
9	Mg	%	0.43	0.46
10	S	%	0.35	0.21
11	Ba	%	0.068	0.054
12	P	%	0.042	0.044
13	Mn	%	0.035	0.029
14	Cr	%	0.025	0.020
15	Sr	%	0.017	0.016
16	Ni	%	0.016	0.011
17	Zr	%	0.016	0.0137
18	Cl	%	0.011	0
19	Rb	%	0.011	0.011
20	V	%	0.010	0.013
21	Cu	%	0.010	0.008
22	Zn	%	0.008	0.0076
23	Pb	%	0.006	0
24	W	%	0.004	0
25	Ga	%	0.0034	0.022
26	Others	%	0.0061	0.0041

As shown in table 2, the aluminum content in the two waste dumps from Jiu Valley (which is extrapolated to be the same for the other two waste dumps, Livezeni and Lupeni) is in a considerable concentration, of approx. 10% on average, in other words, it can be recovered a theoretical amount of 0.495 million t of aluminum.

Recovery of aluminum on economic basis

The concentration that is found in the waste dump's material complies with the minimum average useful content for aluminum ore (6-8%) [3,4]. This led to the idea of analyzing the opportunity of recovery and capitalization of this element from the four active dumps from Jiu Valley.

For the recovery of aluminum to be economically viable the following relationship (1) must be satisfied [5]

$$c_{med_{\min}} = \frac{P}{p \cdot \eta - M} \cdot \frac{1}{k \cdot m} \qquad [\%] \qquad (1)$$

where

c_{medmin} - minimum average useful content %;

P - costs of mining and ore preparation USD/t;

p - the selling price of the metal USD/t;

η - efficiency of metallurgic extraction;

k - coefficient that during the appreciation of the advisability of operation has the value equal to 1;

M - all metallurgical processing costs USD/t;

m - extraction of metal in the concentrate %.

Since this paper assumes that only the primary processing will take place in Jiu Valley, separation of bauxite from the rest of waste rocks from the dumps in order to obtain a concentrate to be submitted later (in another location) for metallurgical processing and refining processes, not all the values of the parameters involved in relation (1) can be set.

However, the relationship can be simplified and some judgments can be made on the opportunity to recover aluminum from the active waste dumps, given the average price of 99.7% pure aluminum on the world market for the last 5 years (figure 4).

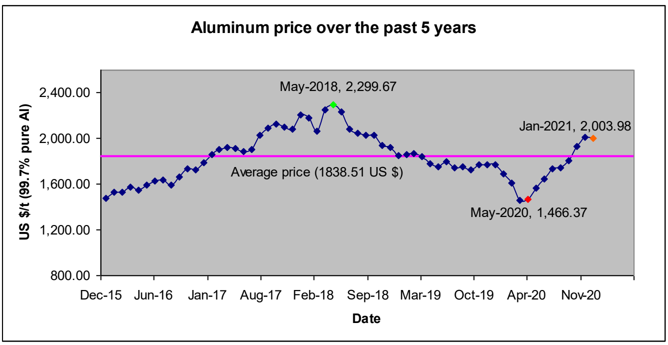

Fig. 4. Price per metric ton of aluminum (99.7% purity) [17]

As can be seen from figure 4, the price of aluminum on the international market has undergone significant variations in the last 5 years. If in May 2018 the price per ton of aluminum reached almost 2,300 USD, in May 2020 it recorded the lowest value in the analyzed time period, of only 1,466 USD/t.

Although the average value calculated for the price of aluminum is approx. 1,838 USD per ton, the authors believe that the period corresponding to 2020 should be eliminated, which would lead to an increase in the average price to approx. 1,875 USD per ton (value that will be considered representative further in the paper).

The sudden drop in price followed by an equally sudden rise from 2020 does not reflect the normal behavior of the world market, this variation being obviously a reaction to the restrictive measures adopted by most countries in the world in the effort to manage the crisis caused by the SARS-CoV-2 (COVID 19) pandemic.

Substituting the known values into relation (1), this becomes (2)

$$10 = \frac{P}{1875 \cdot \eta - M} \cdot \frac{1}{m} \quad [\%] \qquad (2)$$

If we analyze relation (2), the minimum average useful content is constant and the cost of extraction and preparation is much lower than for operating a bauxite quarry (this cost decreases because we are not talking about an actual exploitation but an excavation and transport of the waste material from the dumps to a processing plant and therefore the largest share in this cost will be held by ore processing rather then mining).

As the other technological parameters depend on the performance of machines and equipments (and their value varies generally in known limits) we can say that the most important variables in determining the appropriateness of recovery of aluminum are the costs of metallurgical processing (especially the influence of the electricity price) and the selling price on the world market of aluminum.

So according to these variables it can be established the appropriate time to recover the aluminum contained in the dumps from Jiu Valley, meaning that they can be reprocessed in sequences, when the values of the variables mentioned satisfies equation (2) (or when the calculated minimum average useful content is below 10).

Primary processing

For processing the material from the active waste dumps from Jiu Valley, in order to separate the bauxite from the rest of the rocks, the technological flux shown in figure 5 is proposed.

The material (which can be assimilated with a low-grade ore) deposited in the waste dumps, with a granulometry up to 200 mm, is excavated and transported towards the processing plant by trucks.

Here, the material is subjected to a primary grinding stage, using an autogenous mill.

Primary crushed material obtained in the discharge of the autogenous mill is volumetrically classified at 3 and 1 mm on a vibrating screen with two superimposed filing surfaces, on which acts powerful jets of water (to remove clays) [10].

Refusal of the 3 mm surface is returned to the autogenous mill, while the refuse from the 1 mm surface (fraction ranging from 1 mm to 3 mm) is then subjected to the separation process in dense medium (first stage), obtaining a concentrate and a sludge. Fine fraction -1 mm is subject to hydrocyclonage at 0.3 mm separating the predominantly clayey slurry from the bauxite. Refusal product from the hydrocyclone (fraction between -1 and +0.3 mm) is driven to the second stage of separation in dense medium, obtaining a concentrate (which is united with the concentrate obtained in the first stage of separation in dense medium) and a sludge [8].

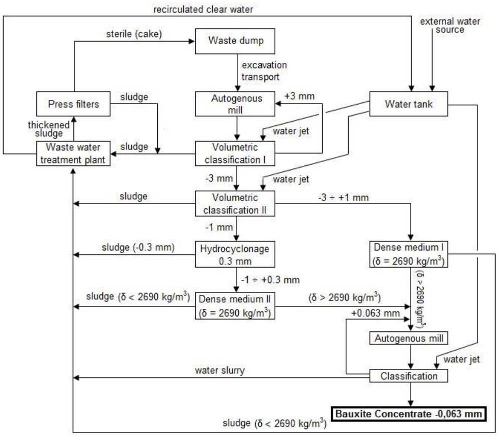

Fig. 5. Primary processing flux (modified after [8])

The second stage of grinding and advanced washing of bauxite is designed to bring the particle size to -0.063 mm, size necessary to obtain good extraction efficiencies in the Bayer process [10, 14, 15].

The sludge resulted from the primary and secondary volumetric classifications, hydrocyclonage and separation in dense medium as well as the water slurry resulted from the last classification is driven through the waste water treatment plant.

The thickened sludge goes into batteries of press filters. The resulted slurry is driven back to the waste water treatment plant and the sterile rocks (cakes) are transported back to the waste dump.

The resulting clear water will be recycled in the process.

Metallurgical extraction and refining

Bayer technology (alkaline process)

In this process, the aim is to convert aluminum hydroxides from bauxite ores to sodium aluminate. In Romania, this procedure is applied in metallurgical plants from Oradea, Slatina and Tulcea.

The following main steps can be distinguished in Bayer technology (figure 6): leaching, dilution, decomposition, and concentration [6].

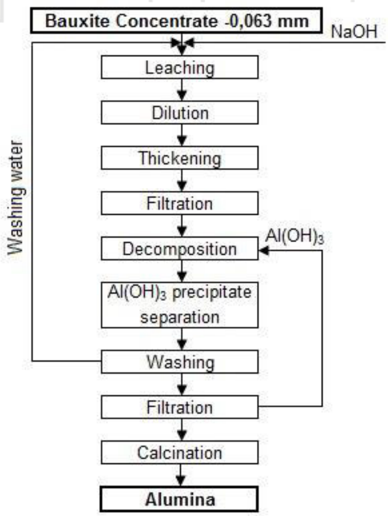

Fig. 6. Schematics of Bayer process [4]

Solubilization is performed with sodium hydroxide, in autoclaves, under pressure. In this stage reaction (3) takes place

$$Al_2O_3 . H_2O + 2\,NaOH = 2\,NaAlO_2 + 2\,H_2O . \qquad (3)$$

The other compounds present in bauxite interact with alkaline solutions, forming sulfates, hydroxides, vanadates and phosphates that can be precipitated from recycled solutions, under different technological conditions [3].

The bauxite ore (already grounded to sizes less than 0.063 mm) is put in contact with a concentrated solution of sodium hydroxide and placed in autoclaves at temperatures of 150-250 °C.

From the autoclave, the slurry is passed into wet tanks and diluted, followed by a series of successive settlements and filtrations of the diluted solution to separate the sodium aluminate from the residue in suspension. The obtained solution is subjected to the decomposition operation. The most important feature of these solutions is the caustification ratio (4) - which is the molar ratio between alkaline oxides and alumina present in the solution [3, 4]

$$\alpha_k = \frac{Na_2O_k}{Al_2O_3} \qquad (4)$$

The decomposition is carried out by slow cooling (in 70-80 hours to reach a temperature of 20 °C) during which the concentrated solution of sodium aluminate hydrolyzes, with the precipitation of $Al(OH)_3$ according to reaction (5) [3, 4]

$$NaAlO_2 + 2\,H_2O = NaOH + Al(OH)_3 \qquad (5)$$

After filtration, the aluminum hydroxide is calcinated in rotary ovens at temperatures of 1,200 – 1,400°C. The purpose of calcination is to dehydrate the aluminum hydroxide as completely as possible and to obtain non-hygroscopic alumina according to reaction (6) [4, 15]

$$2\,Al(OH)_3 \rightarrow \gamma Al_2O_3 \rightarrow \alpha Al_2O_3 \qquad (6)$$

Obtaining aluminum from alumina

It consists of electrolysis of alumina dissolved in a salt melt. The electrolysis medium is a melt of cryolite (mixture of aluminum and sodium fluoride) and calcium fluoride.

The alumina is mixed with the melt at a temperature of 940 - 960°C and decomposes releasing aluminum ions Al^{3+} and AlO_3^{3-} anions, according to reaction (7) [11, 14].

$$Al_2O_3 \rightarrow Al^{3+} + AlO_3^{3-} \tag{7}$$

The aluminum thus obtained is deposited on the bottom of the electrolysis bath, having a purity of 99.5-99.7% (which is also the purpose of this proposed project).

Along with aluminum, Cu,Si,Fe,Ti,Ca and non-metallic inclusions are deposited, which is why the product must be further subjected to electrolytic refining (after which 99.99% pure aluminum is obtained) [4,5,15].

Economic and social benefits

By leveraging all of the aluminum estimated to be present in the dumps of Jiu Valley, of 0.495 million t, at the average world market price of 1,875 USD/t results in a total revenue of 928,125,000 USD (this amount needs to balance all operating costs, wages and bring a decent profit).

Also, beyond the obvious economic benefits, we must consider the opportunity to solve some social problems that appeared in Jiu Valley since the mid-90's, when the coal mining exploitations (16 at the time) began to close, on the account of a so-called restructuring program [9] (currently only 4 mines being still in operation).

We are referring here at the problem of unemployment (the real unemployment rate in Jiu Valley is estimated to be almost double compared to the national one) and the lack of alternative jobs.

By reprocessing the four active waste dumps from Jiu Valley for the recovery of useful minerals (aluminum as proposed in this study) would create, at least for a period of time, jobs, which would largely address the people dismiss from the mining and mineral resources processing sectors.

Environmental benefits

To identify the environmental effects (benefits) it should be noted that the chemical analysis revealed the concentration of metallic aluminum in the active waste dumps to be of approx. 10% on average. This aluminum is actually present in bauxite and if we consider that in Romania the bauxites have an average content of

50% Al [16], results in a simple calculation that by reprocessing the four waste dumps (separation of bauxite from the rest of the rocks) the volume of stored material decreases by about 20%.

For a total volume of sterile approx. 2.72 million m^3 results a decrease by approx. 544,000 m^3, which by extrapolation leads to a decrease in the total area occupied by waste dumps of approx. 3 ha.

Another advantage from the point of view of environmental protection is represented by the reduction of the contamination risk with Al^{3+} of the adjacent natural terrains.

To explain this benefit we must take into consideration that in Jiu Valley operates a power plant (CET Paroşeni). This power plant produces electricity and hot water using coal (as the main fuel) extracted from the four still operating mines in the area. This clarification is necessary because the coal extracted from Jiu Valley has a relatively high sulfur content, sulfur that after the combustion process is released into the atmosphere in appreciable quantities in the form of SO_2 (although a desulphurization installation was put into operation a few years ago). Also, from combustion processes, results appreciable quantities of NO_x.

The two above-mentioned residual combustion gases are, as is known, responsible for the formation of acid precipitations. Once in contact with rocks from the waste dumps containing aluminum, the Al^{3+} ion is released. In turn it migrates into the soil and replaces calcium in its connections, resulting in a decrease of the intake of nutrients, with negative consequences in terms of plant resistance to insects, disease or excessive climate [1, 2].

Finally, recovery of aluminum from the waste dumps should be seen as an environmental protection action if we take into account the fact that it can provide a significant amount of this metal for the domestic market without requiring to put into service new conventional bauxite deposits, which certainly would generate a significant direct negative impact on the environment and would require a supplementary energy consumption.

Conclusions

Recovery of aluminum contained in the four active waste dumps from Jiu Valley is possible if we take into account the concentration of this element (10% minimum average useful content compared to 6

- 8% considered exploitable at present) and the significant reduction in operating costs compared to those claimed when operating a conventional bauxite quarry (basically we are talking about an excavation of waste dumps instead of complex mining operations in bauxite quarries).

To ensure the economic efficiency of the aluminum recovery process from the four considered waste dumps, their operation can be performed sequentially by considering the most important variables (price of electricity and aluminum) so that the relationship between the average minimum useful content and the mentioned variables is satisfied at any moment in time.

From an environmental perspective, the recovery of aluminum has advantages as it reduces the risk of soil contamination with aluminum ions in the vicinity of the waste dumps, the volume and the areas occupied by waste dumps are reduced and for a period of time we avoid to generate a negative impact on the environment (by not putting into exploitation conventional bauxite deposits).

Such an activity, of recovering aluminum from waste dumps is beneficial economically and socially by providing employment for a significant period of time for the residents of Jiu Valley and it complies with international policies on secondary resource exploitation, environmental protection and sustainable resource management.

References

1. **Andersson M.** Toxicity and tolerance of aluminum in vascular plants, Water, Air, & Soil Pollution. Vol. 39, No. 3–4, pp. 439–462. doi:10.1007/BF00279487, 1988.

2. **Apostu I.M., Faur F., Lazăr M.** Identification and assessment of the environmental impact generated by the implementation of Certej Mining Project, Research Journal of Agricultural Science, ISSN 2066-1843, Vol. 48, Nr. 4, pp. 254-264, 2016.

3. **Bădulescu C.** Preparation and metallurgical processing technologies of concentrates (in Romanian), Universitas Publishing House, ISBN 973-8035-15-5, 160 p., Petrosani, Romania, 2000.

4. **Bădulescu C.** Techniques and technologies in the metallurgical industry (in Romanian), Sitech Publishing House, ISBN 973-657-681-7, 236 p., Craiova, Romania, 2004.

5. **Craig W., Leonard A.** Manufacturing Engineering & Technology, Scientific e-Resources, ISBN 978-1-83947-242-8, 352 p., 2019.

6. **Drozdov A.** Aluminium: The Thirteenth Element, RUSAL Library, ISBN 978-5-91523-002-5, 232 p., 2007.

7. **Faur F.** The elaboration of an environmental monitoring system in Jiu's Valley (in Romanian), Doctoral Thesis, University of Petrosani, Romania, 164 p., 2009.

8. **Faur F., Lazăr M, Dunca E., Ciolea D.I.** Opportunity of recovery and capitalization of useful minerals from waste dumps in Jiu's Valley. Proceedings of the 13th SGEM GeoConference on Science and Technologies in Geology, Exploration and Mining, ISBN 978-954-91818-8-3/ISSN 1314-2704, Vol. 2, 595 - 602 pp., June 16-22, 2013, Albena, Bulgaria.

9. **Faur F., Marchiş D., Nistor C.M.** Evolution of the coal mining sector in Jiu Valley in terms of sustainable development and current socio-economic implications, Research Journal of Agricultural Science, ISSN 2066-1843, Vol. 49, Nr. 4, pp. 110-117, 2017.

10. **Fechete E.** Process for the preparation of diasporic bauxite ore (in Romanian), Invention Brevet, No. 116387, OSIM, Romania, 2001.

11. **Krausz S., Bădulescu C.** Technologies for preparation and metallurgical extraction of concentrates (in Romanian), Universitas Publishing House, 123 p., Petrosani, Romania, 2001.

12. **Lazăr M., Apostu I.M., Faur F.** Methodology for assessing the environmental risk due to mining waste dumps sliding - case study of Jiu Valley. Carpathian Journal of Earth and Environmental Sciences, ISSN 1842-4090, EISSN 1844-489X, Vol. 10, Issue 3, pp. 223-234, 2015.

13. **Lazăr M., Florea A., Faur F.** Research on load carrying capacity of base terrains of the waste dumps in Jiu Valley, Mining Revue, ISSN-L 1220-2053/ISSN 2247-8590, Vol. 20, No. 4, pp. 26-31, 2014.

14. **Lumley R.** Fundamentals of Aluminum Metallurgy: Production, Processing and Applications, Elsevier Science, ISBN 978-0-85709-025-6, 843 p., 2010.

15. **Polmear I.J.** Light Alloys: Metallurgy of the Light Metals (3 ed.), Butterworth-Heinemann, ISBN 978-0-340-63207-9, 362 p., 1995.

16. **Sîli N., Vesa E.M., Faur F., Apostu I.M.** Considerations regarding the evolution of the landscape in the area of the former bauxite quarries from Ohaba—Ponor, ISSN 2066-1843, Vol. 52, Nr. 4, pp. 123-132, 2020.

17. http://www.indexmundi.com/commodities/?commodity=aluminum