UDC 504.5.06
DOI: 10.15587/2706-5448.2024.305237

Wahida Kherfane, Tourkia Tahri, Amina Bouslama, Meriem Ferfar, Hamza Cheniti, Nacer Bezzi, Omar Sekiou, Nadiia Dovbash, Aissa Benselhoub

ANALYSIS OF THE SETTLING PROCESS TO IMPROVE THE QUALITY OF PHOSPHATE PRODUCTS OF THE DJEBEL ONK DEPOSIT

The object of the study is the phosphates of the Djebel Onk region, which are part of a vast group of phosphate deposits formed in the Late Cretaceous-Eocene period on the South and Southeast Mediterranean shores. These concentrations of economic interest are operated near the town of Bir El Ater (Tebessa, Algeria). The mining industry based on the extraction and processing of different minerals while respecting the environmental framework plays an important role in the economy of a country. The economic potential of each country will be determined based on the level of production of metals and various mineral substances. In the case of the Djebel Onk phosphate ore, the most dominant mineral in addition to P_2O_5 is calcium carbonate $CaCO_3$ with more than 50 % in the all-mineral content. In addition, phosphate concentrate contains harmful elements which reduce the value of the market product. Therefore, this study aims to recover the enriched product efficiently and profitably with a minimum of deleterious elements. This work aims to develop a treatment technology with a minimum rejection rate, which allows for achieving production goals and reducing environmental impacts. For this purpose, we proposed an enrichment of these phosphate discharges from the settling process utilizing pneumatic selection (Turbo Separator Ventilate – TSV). The results of the chemical analyses confirm the significant difference in useful and major elements (P_2O_5) and the minor and harmful elements (MgO). According to the granulochemical analysis of each slice, it is possible to note that the P_2O_5 content is similar to the various particle-size slices. It is therefore necessary to treat the mass of waste if we want to recover as much phosphate as possible. The obtained X-ray diffractograms highlighted appreciable differences between the raw phosphates and the concentrates, in fact, the qualitative and quantitative variation of the mineralogical species, particularly the calcite, quartz, dolomite, and apatite. TSV is a process used to improve the quality and quantity of phosphate and to eliminate the layer below 0.8 mm. Corresponding to the analyses it was appeared that the P_2O_5 content 29.5–30 % of the settled product increases to 30.2–31 % after dust removal. Then it is possible to achieve an increase in the quality of phosphate from 63/65 % TPL to 66/68 % TPL.

Keywords: *phosphate ores, settling process, TSV, major elements, quality improvement, Tebessa, Southeast Algeria.*

Received date: 29.03.2024
Accepted date: 29.05.2024
Published date: 03.06.2024

How to cite

Kherfane, W., Tahri, T., Bouslama, A., Ferfar, M., Cheniti, H., Bezzi, N., Sekiou, O., Dovbash, N., Benselhoub, A. (2024). Analysis of the settling process to improve the quality of phosphate products of the Djebel Onk deposit. Technology Audit and Production Reserves, 3 (3 (77)), 11–17. doi: https://doi.org/10.15587/2706-5448.2024.305237

1. Introduction

Phosphate deposits were formed at the end of the Cretaceous-Eocene in the region of Djebel Onk. Deposits in this region contain a variety of trace elements, including lead and chromium, which exceed the requirements of the mineral industry [1]. The formation of these deposits is influenced by factors such as structural disturbance, tectonic activity, and deposit [2]. Petrological, geochemical, and biostratigraphic studies have been carried out to understand the factors that influenced the enrichment and deposition of its phosphorite deposits [3]. The phosphorite deposits in the Djebel Onk region are characterized by their stratification, their internal structure, and their deposition in a coastal environment [4]. The deposits are composed of phosphate substances such as kuskite, which reflect different generations and diagenetic stages of phosphorite formation [5]. These phosphorite deposits constitute important resources and their formation and characteristics have been the subject of extensive study. The economic operation near Bir El Ater locality which contains significant reserves of phosphate ores aims to improve the P_2O_5 content of phosphate ore tailings and bring economic value to the mining district [6, 7]. The mining industry is crucial for the economic development of the country. The industry contributes significantly to the national Gross Domestic Product (GDP), exports, and job creation, which promotes regional and rural development [8].

ISSN 2664-9969

Djebel Onk is known for its phosphate deposits, making it a leading global phosphate exporter [1]. However, mining activities in Djbel Onk and other regions have negative environmental impacts, including changes to the natural landscape and severe environmental consequences [9]. Despite challenges, the mining sector has the potential to benefit the national economy and local communities in various ways [10]. Therefore, management and regulation of the mining industry, including waste treatment and efficient use of natural resources, are essential for sustainable development and environmental protection [11].

Mining companies face various technical and scientific challenges in the course of their activities. These challenges include the need for innovative modernization of mining equipment and increased reliability, widespread adoption of Industry 4.0 technologies, transition to green mining, and improved workplace safety and accident prevention [12]. There are also gaps in board assurance of technical and operational risks, particularly with geotechnical risks, requiring a better understanding of the technical complexity and variability of operations mining [13]. Improving ore processing technology involves the development and implementation of new technologies and methods aimed at improving the efficiency and effectiveness of the extraction and processing of metal ores. This includes the combination of traditional and new technologies, such as the leaching of metals from ores contained in underground blocks and the use of disintegrator-type activators [14].

The mining industry has recorded progress in ore processing through the use of new technologies [14–16]. These advancements include the use of advanced machinery and equipment, which has made mining operations more efficient and productive [17]. Additionally, there is a trend toward processing man-made waste accumulated over the years as traditional ore deposits become depleted. The combination of traditional and new technologies has been identified as a priority direction for the extraction and beneficiation of metal ores.

The ongoing challenges related to phosphate releases require special attention due to the potential environmental risks associated with the presence of heavy metals in the releases. Various research studies have been carried out to develop methods for the recovery of Phosphorus (P) from different waste resources including food waste, manure, mining waste, and sewage sludge [18]. Additionally, the management of phosphate waste from mining operations is crucial to avoid harming the local environment. A new approach based on the intrinsic properties of the minerals present has been proposed for the recovery of phosphate waste, to control impurities and reuse them in the mining complex [1]. *This study aims* to recover the enriched product efficiently and the development of a treatment technology with a minimum of rejection, which allows for the achievement of these production objectives and reduces its environmental impact. *For this purpose*, an enrichment of these phosphate wastes from the settling process utilizing pneumatic selection is proposed (TSV – Turbo Separator Ventilate).

2. Materials and Methods

2.1. Study zone description. The phosphates of Djebel Onk region located in southeastern Algeria, 100 kilometers southwest of Tebessa and 20 km from the Algerian-Tunisian border, are part of a vast group of phosphate deposits formed in the Late Cretaceous–Eocene period on the South and Southeast Mediterranean shores [1, 19, 20]. The localization map of the Djebel Onk region is illustrated in Fig. 1.

Fig. 1. Localization map of the study zone (QGIS open-source)

The phosphate deposit geology of the Djebel Onk region is relatively simple; and is constituted by the stratification of layers that pass from Maastrichtian at the base to the Miocene at the top, surmounted by Quaternary deposits made up of scree and sandy alluvial formations. The phosphate mineralization of the deposit is of an upper Thanetian age, represented by layers that can rich more than 30 m thick [21–23].

2.2. Physicochemical characterization of phosphate ore from Djebel Onk. The raw phosphate samples were studied from the Djebel Onk (Tebessa, Algeria). The physicochemical and mineralogical characterization of these samples was performed by various quantitative and qualitative analysis methods to define the mineralogical and chemical characteristics. The distribution of the chemical contents of major elements of the studied raw phosphate ore samples is presented in Table 1.

Table 1

Chemical analyses by granulometric classes of the phosphate sample

Granulometric size fractions, mm	% by mass		
	P_2O_5	CO_2	MgO
<0.1	18.47	6.6	5.89
+0.1–0.5	28.5	7.5	1.26
+0.5–0.8	26.12	8.7	2.08
+0.8–1	23.06	11.8	3.91
>1	21.4	14.13	5.13
Overall	28.1	6.6	1.28

The results of the chemical analyses confirm the significant difference in useful and major elements (P_2O_5) and the minor and harmful elements (MgO).

2.3. X-Ray diffraction analysis (XRD). The analysis was conducted on the raw, settled, and dust-removed phosphate samples. The diffractograms were performed using an X'Pert

PRO diffractometer (made in the UK), an X-ray tube with a copper anticathode. The obtained X-ray diffractograms highlighted appreciable differences between the raw phosphates and the concentrates, in fact, the qualitative and quantitative variation of the mineralogical species, particularly the calcite, the quartz, dolomite, and apatite.

A clear reduction in the intensity of the line's characteristic of carbonates and quartz in phosphate concentrates, obtained from dust removal, and its importance in the crudes and the settled product, with, however, a relatively important phosphate phase in the concentrates.

2.4. Microscopic observations. The microscopic observations carried out on of dust-removed product of phosphate samples, previously prepared, were performed using a binocular ZEISS STEMI 2000-C magnifying glass (made in Germany). The result is shown in the Fig. 2.

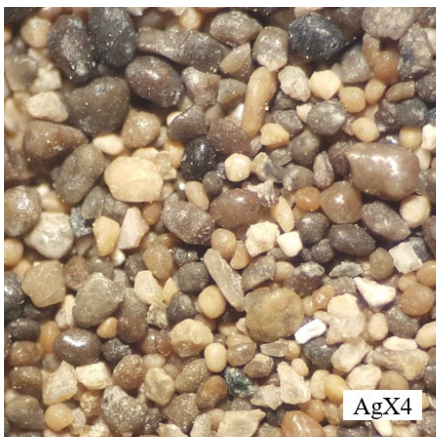

Fig. 2. Microscopic observations of dust-removed product of phosphate samples with a binocular magnifier [1]

2.5. Turbo separator ventilate – TSV. TSV is a third production classifier for separation in the turbine blade channels. The particles are subject to two opposing forces: centrifugal force due to the rotation of the turbine and drag force due to the centripetal arrival of gases.

The purpose of the installation of the dry track is to obtain, through a more efficient pneumatic selection, an increase in production as well as an increased quality of the finished product, and this is based on the turbine speed parameters of the TSV and supply flow, the control of these parameters decides on the optimization of the quality produced.

The crushed ore is transported to pneumatic blade selectors whose operating principle is as follows:

– The crushed product cascades over a series of superimposed shutters and a current of air passes between the shutters.
– For a given airspeed, all particles with a dimension greater than 0.08 mm cascade down to the bottom of the selector without being carried away by the air current.
– Particles with a dimension the air current carry less than 0.08 mm through the blades.

In general, at the level of the selectors, an operation is carried out such that the fines rise by an ascending air current towards the bag filters, and the large particles fall under the effect of their weight.

The granulochemical results of the settling supply materials are given in Table 2.

Table 2

Granulochemical results of settling supply materials

Products	Particle size slices, mm	Weight, %	P_2O_5, %	CO_2, %	MgO, %
Supply TSV: 86 tr/mn SAS: 600 tr/mn	Overall	99.99	29.45	7.29	1.40
	+0.5	4.54	28.90	7.95	/
	+0.1	81.80	30.05	6.46	/
	+0.09	1.30	25.80	11.26	/
	–0.09	12.35	24.95	12.25	/
	Overall weighted		29.31	7.30	/
Big TSV: 86 tr/mn SAS: 600 tr/mn	Overall	100	30.15	6.30	0.88
	+0.5	3.06	28.80	7.95	/
	+0.1	95.61	30.28	6.13	/
	+0.09	0.89	27.80	8.94	/
	–0.09	0.44	26.70	10.60	/
	Overall weighted		30.20	6.23	/
Fines TSV TSV: 86 tr/mn SAS: 600 tr/mn	Overall	100	25.80	11.26	3.80
	+0.5	49.85	26.45	10.60	/
	+0.1	50.15	25.20	11.92	/
	Overall weighted		25.82	11.26	/

Note: TSV – Turbo Separator Ventilate; SAS – Sieve Analysis System

Following the performance tests relating to the TSV and after analyzing the particle size and chemistry of the product outgoing the TSV we observed the following:

– The 0.09 mm low cutoff portion is 0.5 % which confirms its goodness as well as its effectiveness.
– Given that the weight yield is an essential element to know our weight loss, the machine was able to show an encouraging yield of 74 % or 26 % loss.

3. Results and Discussion

The results of proposed enrichment of phosphate wastes from the settling process utilizing pneumatic selection (Turbo Separator Ventilate – TSV) are demonstrated in Fig. 3–5.

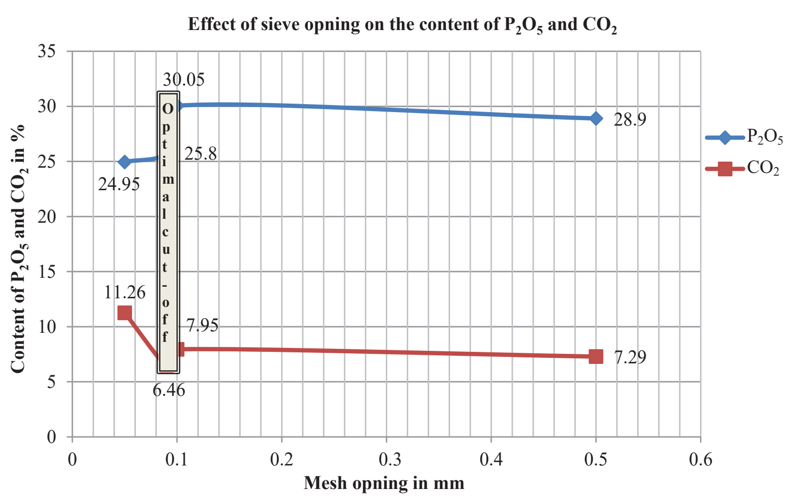

Fig. 3. Product supplying TSV

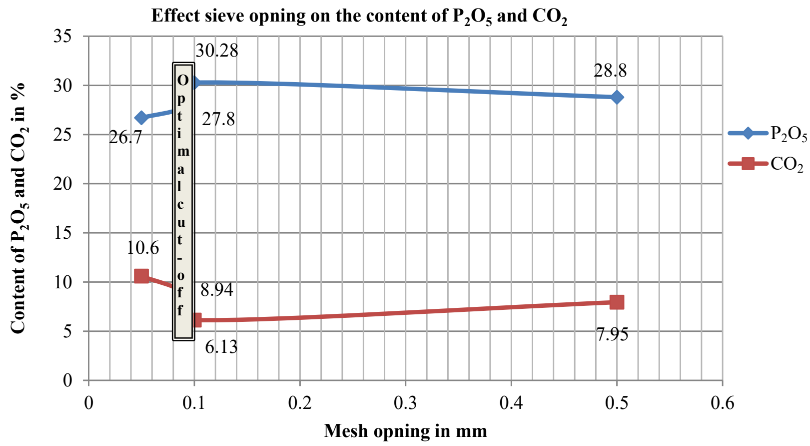

Fig. 4. Product outgoing the TSV

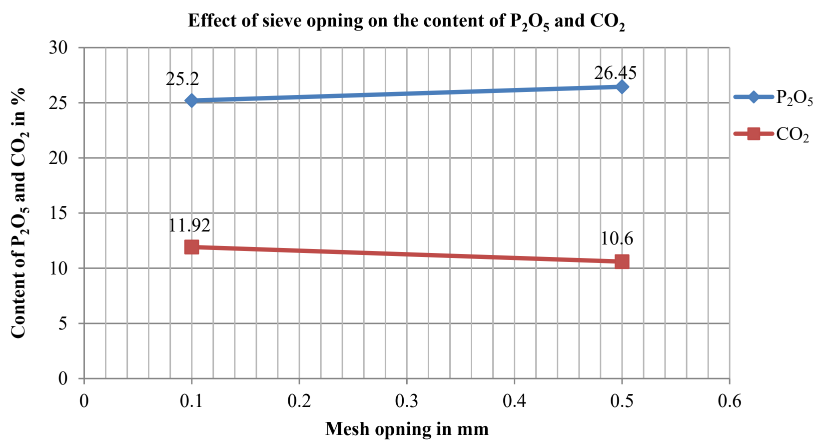

Fig. 5. Fines from the TSV

Fig. 3 shows that the P_2O_5 content increases when the CO_2 content decreases. Moreover, the P_2O_5 content of samples with dimensions greater than 0.08 mm and less than 0.1 mm was found to be high; on the other hand, the slices greater than 0.1 mm and the thin ones (<0.08 mm) were reduced.

Fig. 4 shows that the P_2O_5 content increases when the CO_2 content decreases. However, the percentages of P_2O_5 in the section (–0.08+1 mm) of outgoing products increase by contribution to the supply, and the percentages of CO_2 are reduced.

Fig. 5 shows that the P_2O_5 content increases when the CO_2 content decreases.

Nevertheless, the P_2O_5 content of the fines is reduced by contribution to the outgoing product; however, the CO_2 content is increased.

3.1. Granulochemical analyzes of the settled material. In the settling workshop, the screened product with a particle size <2 mm undergoes classification, which essentially consists of eliminating the external silica from the exogangue as well as the clays. In the settled ore, it is below 100 microns that there is a sudden depletion of phosphate, compensated by an increase in silica and dolomite (Table 3).

Under these conditions, a too imprecise particle size cut-off during desliming (low cut-off) will lead to a significant reduction in the content of the settling. The settled ore has an average content of 65 % DWT; the ore undergoes purely physical treatment. The workshop weight yield is 72 %, thickeners with a diameter of 50 m for the decantation of clayey sludge. The overflows are collected in a buffer basin.

Table 3

Granulochemical analyzes of the settled material

Products	Particle size slices, mm	Weight, %	P_2O_5, %	CO_2, %	MgO, %
Settling supply	+1	17.52	21.80	14.00	4.99
	+0.8	1.31	24.20	11.50	3.34
	+0.5	5.01	27.40	8.30	1.92
	+0.1	69.66	28.50	7.30	1.39
	–0.1	66.49	19.00	7.00	5.96
	Overall	99.99	28.00	7.00	1.51
Settled product	+0.5	4.54	27.30	8.70	2.38
	+0.1	88.38	30.10	6.70	1.06
	–0.1	7.07	20.00	10.70	6.74
	Overall	99.99	29.70	7.40	1.13

Fig. 6 shows that the P_2O_5 content increases when the CO_2 and MgO content decreases.

Also, the P_2O_5 content of samples with dimensions greater than 0.08 mm and less than 0.1 mm was found to be high; on the other hand, the slices greater than 0.1 mm and the thin ones (<0.08 mm) were reduced.

Fig. 7 shows that the P_2O_5 content increases when the CO_2 content decreases.

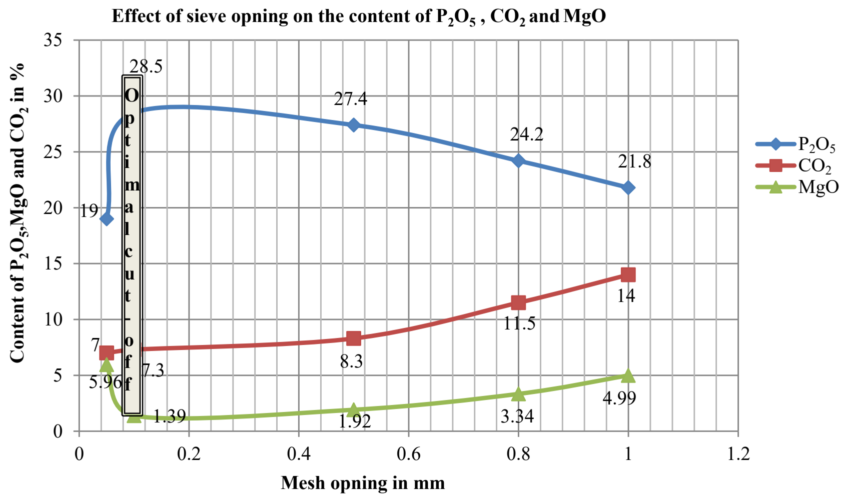

Fig. 6. Product supplying settling

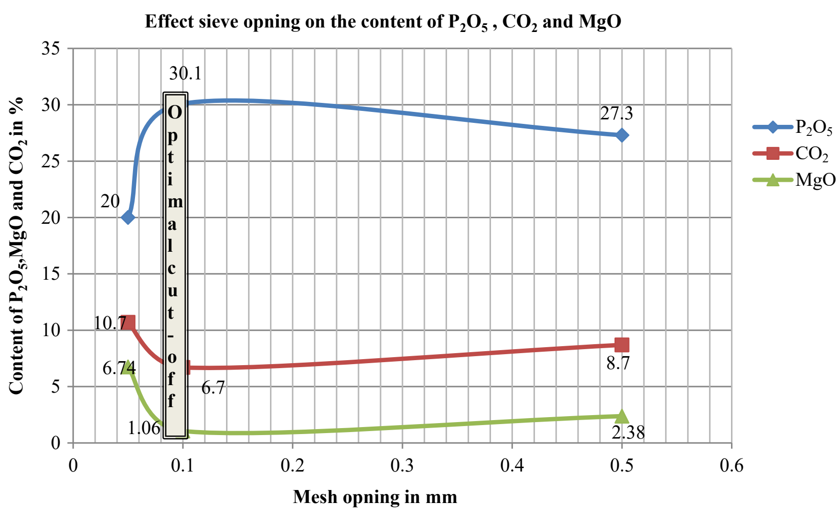

Fig. 7. Settled products

Though the P_2O_5 content of the fines is reduced compared to the outgoing product, the CO_2 content is increased.

3.2. Manufacturing of phosphates fertilizers. In the settled ore, it is below 100 μm that there is a sudden depletion of phosphate, compensated by an increase in silica and dolomite. Under these conditions, a too imprecise particle size cut-off during desliming (low cut-off) will lead to a significant reduction in the content of the settling to eliminate the fines (<0.08 mm) see Fig. 8 and Table 4.

Fig. 8. Phosphate 63/65TPL settled product

The basic raw material for phosphate mineral fertilizers is natural calcium phosphate extracted from deposits, the largest of which are located in Morocco, the USA, Russia, and the Middle East. A second raw material is Sulfur used for the manufacture of sulfuric acid which makes the phosphate more soluble. One of the manufacturing processes for mineral phosphate fertilizers consists of first manufacturing sulfuric acid (H_2SO_4) by combustion of sulfur and absorption of the sulfur trioxide (SO_3) formed. A second raw material is Sulfur used for the manufacture of sulfuric acid which makes it possible to make the phosphate more soluble than mixing the acid and the finely ground natural phosphate to obtain the simple Superphosphate which contains 18 to 25 % P_2O_5.

Another process consists of manufacturing phosphoric acid (H_3PO_4) by attacking the natural phosphate with concentrated sulfuric acid, with the elimination of the calcium sulfate (phosphogypsum) then reacting the phosphoric acid with the natural phosphate to obtain the Triple superphosphate (TSP): it contains 38 to 45 % P_2O_5.

Table 4

Technical data sheet of the 63/65TPL phosphate quality of the settled product

Major Elements	Content, %
Phosphoric Anhydride (P_2O_5)	29.50 to 30.00
Carbonic Anhydride (CO_2)	7.2 to 6.5
Sulfuric Anhydride (SO_3)	3.00 to 2.30
Calcium oxide (CaO)	49.00 to 50.00
Magnesium Oxide (MgO)	1.00 to 0.80
Iron oxide (Fe_2O_3)	0.40 to 0.35
Aluminum oxide (Al_2O_3)	0.35 to 0.40
Sodium Oxide (Na_2O)	1.10 to 1.20
Potassium Oxide (K_2O)	0.10 to 0.09
Silicon Oxide (SiO_2)	3.00 to 2.50
Humidity (H_2O)	0.90 to 0.70
Loss on ignition (CO_2 deducted)	2.80 to 2.75
Fluorine (F)	3.60 to 3.70
Chlorine (Cl) in ppm	400 to 500
C-Org	0.10 to 0.20
P_2O_5 Soluble in 2 % citric acid	10.50 to 10.00
P_2O_5 Soluble in 2 % formic acid	20.00 to 18.00

According to the analyses, it appears that the P_2O_5 content (29.5 to 30 %) of the settled product increases to (30.2 to 31 %) after dust removal. Then it is possible to achieve an increase in the quality of phosphate from 63/65 % TPL to 66/68 % TPL.

3.3. Limitation and prospective research. Phosphate mining can have numerous negative repercussions on the environment, including deforestation and destruction of natural habitats, alteration of landscapes, soil erosion, air and water pollution, degradation of water quality, impact on biodiversity, and risks to human health.

Mining activity is increasing in Algeria and is vital to the country's economic development. However, it has many challenges to overcome to do so, and must solve important technical and scientific questions related to ore processing:
- improvement of processing technologies;
- recovery and treatment of phosphate waste while respecting the environment;
- establishment and introduction of the automatic control system.

The objective in this case is to develop a treatment technology with minimal rejection, which allows mining companies to achieve production targets and reduce environmental impacts. To achieve this, it is necessary to:
- recovery of waste from the production chain to extract P_2O_5 and carbonates in the form of CaO and MgO;
- use other treatment processes to eliminate heavy metals or any other element that could harm the quality of the commercial product.

Indeed, the mining industry continues to make great progress when using new technology for ore processing. However, despite this industrial revolution, the treatment of waste remains a hot topic. These releases are certainly low in content but can be recovered by adopting appropriate technology for these purposes. They can also contain heavy metals which will cause serious environmental problems if they are not treated. In addition, these non-renewable resources must be recovered in a very profitable way for the population that lives them to be able to be part of the logic of sustainable development.

4. Conclusions

The obtained results of the chemical analyses confirm the significant difference in useful and major elements (P_2O_5) and the minor and harmful elements (MgO). According to the granulochemical analysis of each slice, let's note that the P_2O_5 content is similar to the various particle size slices. It is therefore necessary to treat the mass of waste if we want to recover as much phosphate as possible.

The obtained X-ray diffractograms highlighted appreciable differences between the raw phosphates and the concentrates, in fact, the qualitative and quantitative variation of the mineralogical species, particularly the calcite, the quartz, dolomite, and apatite.

This work aims to develop a treatment technology with a minimum rejection rate, which allows for achieving production goals and reducing environmental impacts. For this purpose, an enrichment of these phosphate discharges from the settling process utilizing pneumatic selection is proposed (Turbo Separator Ventilate – TSV). The TSV is a process used to improve the quality and quantity of phosphate and to eliminate the layer below 0.8 mm. According to the analyses, it was appeared that the P_2O_5 content 29.5–30 % of the settled product increases to 30.2–31 % after dust removal. Then it is possible to achieve an increase in the quality of phosphate from 63/65 % TPL to 66/68 % TPL.

Acknowledgment

The authors would like to express their thanks to the National Company SOMIPHOS subsidiary of the FERPHOS Group operated near the Bir El Ater (Tebessa, Algeria) for the fieldwork access and assistance, and to the Laboratory LTMGP of the University of Bejaia, as well as the Mining Laboratory of Istanbul Technical University (Istanbul, Turkey) for several analyses.

Conflict of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

The paper has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

References

1. Tahri, T., Narsis, S., Bezzi, N., Grairia, A., Benghadab, K. M., Benselhoub, A. (2023). Environmental polluting effects of liquid wastes and phosphate sludge generated by the Djebel Onk mining complex. *Journal of Geology, Geography and Geoecology, 32 (1),* 178–184. doi: https://doi.org/10.15421/112317
2. Salah, S., Ismail, N., Mohamed Cherif, D. (2023). Application of electrical tomography technique for landslide investigation: Case of the Kef Essenoun phosphate deposit, Djebel Onk (Northeastern Algeria). *Russian Journal of Earth Sciences,* 1–7. doi: https://doi.org/10.2205/2023es000830
3. Krochak, M. D., Mienasova, A. Sh., Olshtynska, O. P. (2022). Phosphatization of rocks and organic remains of the basal horizon of the Lower Eocene of the Middle Dnipro area. *Journal of Geology, Geography and Geoecology, 31 (2),* 343–351. doi: https://doi.org/10.15421/112232
4. Alqudah, M., Abu-Jaber, N., Al-Rawabdeh, A., Al-Tamimi, M. (2023). Paleoenvironmental Study of the Late Cretaceous-Eocene Tethyan Sea Associated with Phosphorite Deposits in Jordan. *Applied Sciences, 13 (3),* 1568. doi: https://doi.org/10.3390/app13031568
5. Dassamiour, M., Mezghache, H., Raji, O., Bodinier, J.-L. (2021). Depositional environment of the Kef Essennoun phosphorites (Northeastern Algeria) as revealed by P_2O_5 modeling and sedimentary data. *Arabian Journal of Geosciences, 14 (12).* doi: https://doi.org/10.1007/s12517-021-07400-z
6. Lihoreau, F., Hautier, L., Mahboubi, M. (2015). The new Algerian locality of Bir el Ater 3: validity of Libycosaurus algeriensis (Mammalia, Hippopotamoidea) and the age of the Nementcha Formation. *Palaeovertebrata, 39.* doi: https://doi.org/10.18563/pv.39.2.e1
7. Mohamed, M. A. K., Ibrahim, G. A. E. A., Rizk, A. M. E., Ahmed, M. M., El Nozahi, A. M., Abdelkhalek, N. A., Bakheat, H. (2018). Upgrading of Phosphate Ore Wastes of El-Nasr Mining Company, Egypt. *International Journal of Mineral Processing and Extractive Metallurgy, 3 (2),* 37.
8. Boumaza, B., Chekushina, T. V., Kechiched, R., Benabdeslam, N., Brahmi, L., Kucher, D. E., Rebouh, N. Y. (2023). Environmental Geochemistry of Potentially Toxic Metals in Phosphate Rocks, Products, and Their Wastes in the Algerian Phosphate Mining Area (Tébessa, NE Algeria). *Minerals, 13 (7),* 853. doi: https://doi.org/10.3390/min13070853
9. Yatsykovskyy, B. (2022). Features of the concept state regulation of national development mining industry. *Herald of Khmelnytskyi National University. Economic Sciences, 306 (3),* 126–130. doi: https://doi.org/10.31891/2307-5740-2022-306-3-18
10. Ali, B., Loubna, B., Leila, B. (2021). Impacts of mining activities on soil properties: case studies from Morocco mine sites. *Soil Science Annual, 71 (4),* 395–407. doi: https://doi.org/10.37501/soilsa/133011
11. Chuluundorj, K., Batdelger, T., Hosoi, Y.; Hosoi, Y., Batdelger, T., Chuluundorj, K. (Eds.) (2022). *Introduction. Economic Dependence of Mongolia on Minerals: Consequences and Policies.* Singapore: Springer Nature Singapore, 159–186. doi: https://doi.org/10.1007/978-981-19-5515-0_1
12. Zhironkin, S., Szurgacz, D. (2022). *Mining Technologies Innovative Development.* MDPI-Multidisciplinary Digital Publishing Institute, 362. doi: https://doi.org/10.3390/books978-3-0365-3224-0
13. Atkins, A., Ritchie, M. (2019). Improving board assurance of technical and operational risks in mining. *Proceedings of the First International Conference on Mining Geomechanical Risk,* 97–110. doi: https://doi.org/10.36487/acg_rep/1905_03_atkins
14. Golik, V. I., Titova, A. V. (2022). Improving the metallurgical resource base through combining ore mining technologies. *Mining Industry Journal (Gornay Promishlennost), 5/2022,* 105–111. doi: https://doi.org/10.30686/1609-9192-2022-5-105-111
15. Vokhidov, B. R., Khasanov, A. S., Nemenenok, B. M., Mamaraimov, G. F. (2022). New directions processing of technogenic waste of the copper industry. *Foundry Production and Metallurgy, 3,* 101–107. doi: https://doi.org/10.21122/1683-6065-2022-3-101-107
16. Kirsanov, M., Gupalo, O., Podoliak, K. (2023). New working fluids for the use of heat secondary sources in mining technologies. *IOP Conference Series: Earth and Environmental Science, 1156 (1),* 012028. doi: https://doi.org/10.1088/1755-1315/1156/1/012028
17. Whitworth, A. J., Forbes, E., Verster, I., Jokovic, V., Awatey, B., Parbhakar-Fox, A. (2022). Review on advances in mineral processing technologies suitable for critical metal recovery from mining and processing wastes. *Cleaner Engineering and Technology, 7,* 100451. doi: https://doi.org/10.1016/j.clet.2022.100451
18. Hosseinian, A., Pettersson, A., Ylä-Mella, J., Pongrácz, E. (2023). Phosphorus recovery methods from secondary resources, assessment of overall benefits and barriers with focus on the Nordic countries. *Journal of Material Cycles and Waste Management, 25 (5),* 3104–3116. doi: https://doi.org/10.1007/s10163-023-01747-z
19. Malaoui, R., Harkati, E. H., Soltani, M. R., Djellali, A., Soukeur, A., Kechiched, R. (2023). Geotechnical Characterization of Phosphate Mining Waste Materials for Use in Pavement Construction. *Engineering, Technology and Applied Science Research, 13 (1),* 10005–10013. doi: https://doi.org/10.48084/etasr.5493
20. Mezam, M. C., Bachar Assed, M. A., Ould Hamou, M., Narsis, S., Benselhoub, A. (2023). A new mining method for reopening the opencast mine of Kef Essennoun. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 4,* 26–32. doi: https://doi.org/10.33271/nvngu/2023-4/026
21. Rebbah, R., Duarte, J., Djezairi, O., Fredj, M., Baptista, J. S. (2021). A Tunnel under an In-Pit Mine Waste Dump to Improve Environmental and Landscape Recovery of the Site. *Minerals, 11 (6),* 566. doi: https://doi.org/10.3390/min11060566
22. Kechiched, R., Laouar, R., Bruguier, O., Salmi-Laouar, S., Kocsis, L., Bosch, D., Foufou, A., Ameur-Zaimeche, O., Larit, H. (2018). Glauconite-bearing sedimentary phosphorites from the Tébessa region (Eastern Algeria): Evidence of REE enrichment and geochemical constraints on their origin. *Journal of African Earth Sciences, 145,* 190–200. doi: https://doi.org/10.1016/j.jafrearsci.2018.05.018
23. Mazari, M., Chabou-Mostefai, S., Bali, A., Kouider, K., Benselhoub, A., Bellucci, S. (2023). Mineral resource assessment through geostatistical analysis in a phosphate deposit. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5,* 141–147. doi: https://doi.org/10.33271/nvngu/2023-5/141

✉***Wahida Kherfane,*** *Doctor of Hydrolycs, Lecturer, Laboratory of Soil and Hydraulic, Department of Hydraulic, Badji Mokhtar University, Annaba, Algeria, ORCID: https://orcid.org/0009-0000-3483-7800, e-mail: kherfanewahida@yahoo.fr*

Tourkia Tahri, *Doctor in Mining Engineering, Lecturer, Laboratory of Materials Technology and Process Engineering (LTMGP), Abderahmane Mira University, Bejaia, Algeria, ORCID: https://orcid.org/0000-0002-3953-9914*

Amina Bouslama, *PhD, Lecturer, Department of Architecture, Badji Mokhtar University, Annaba, Algeria, ORCID: https://orcid.org/0009-0004-5218-7708*

Meriem Ferfar, *PhD, Researcher, Environmental Research Center (C.R.E), Annaba, Algeria, ORCID: https://orcid.org/0000-0002-2028-5213*

Hamza Cheniti, *Doctor of Environmental Sciences, Lecturer, Department of Mining, Metallurgy and Materials, National Higher School of Technology and Engineering, Annaba, Algeria; Chief of the Division of Environment, Modeling and Climate Change Division, Environmental Research Center (C.R.E), Annaba, Algeria, ORCID: https://orcid.org/0000-0001-6544-2537*

Nacer Bezzi, *Professor, Laboratory of Materials Technology and Process Engineering (LTMGP), Abderahmane Mira University, Bejaia, Algeria, ORCID: https://orcid.org/0000-0002-5343-5089*

Omar Sekiou, *PhD, Researcher, Environmental Research Center (C.R.E), Annaba, Algeria, ORCID: https://orcid.org/0000-0003-2727-0740*

Nadiia Dovbash, *PhD, Researcher, National Scientific Centre «Institute of Agriculture of the National Academy of Agricultural Sciences», Chabany, Ukraine, ORCID: https://orcid.org/0000-0002-4741-2657*

✉***Aissa Benselhoub,*** *PhD, Associate Researcher, Environmental Research Center (C.R.E), Annaba, Algeria, ORCID: https://orcid.org/0000-0001-5891-2860, e-mail: benselhoub@yahoo.fr*

✉*Corresponding author*