



ENRICHMENT OF ALGERIAN PHOSPHATE USING COMBINED METHOD TO REDUCE REJECT PRODUCTION

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DOI: 10.2478/minrv-2026-0046

received – 10.03.2026 / revised – 16.03.2026

accepted – 08.05.2026 / published – 22.09.2026

Abstract: *The extraction and processing of mineral resources are considered fundamental pillars of global economic development, given their importance across various sectors. Phosphates are among these strategic resources; the largest reserves are found in Morocco and Western Sahara, Egypt, Tunisia, and Algeria, totaling 2.2 billion tons by 2024.*

In Algerian deposits, two types of phosphate are distinguished: one beige and the other black; this variation is attributed to the significant presence of organic matter. Currently, these two types are processed using dedusting and desliming methods. These methods yield, on the one hand, concentrates with a P_2O_5 content of 29 to 30%; and on the other hand, they result in the loss of useful minerals along with the waste rock. To prevent this loss, a new combined calcination-reverse flotation method is used; this method optimizes phosphate recovery while minimizing waste production. The P_2O_5 content reaches 33.88% with a recovery rate of 97.93%, whereas for the tailings portion, the recovery rate is negligible (2.07%).

The application of these techniques helps prevent waste generation, thereby contributing to the protection of the environment and human health. However, this can also generate other residues due to the use of chemical reagents. To address this issue, waste water can be recycled and treated within the treatment process. Reducing discharge rates and recycling generated waste contribute to the adoption of zero-waste approaches.

Keywords: *Phosphate, processed, Waste, Content, Recovery, Environment*

1. Algerian Phosphate Deposit

The Algerian phosphate deposit of Kef Essenoun mainly consists of two types of phosphate ores: beige phosphate and black phosphate. These ores are subdivided into five phosphatic sub-layers, including three beige sub-layers (basal, upper, and main layers) and two black sub-layers (upper and main layers).

Currently, mining operations are focused on the main beige and main black phosphatic sub-layers, whereas the other three phosphatic sub-layers (the basal beige layer, the upper beige layer, and the upper black layer) are considered waste material.

The processing of these sedimentary phosphates is carried out using two beneficiation methods: desliming and scrubbing. These processes are employed to produce phosphate concentrates containing approximately 29–30% P_2O_5 . However, they also generate large quantities of tailings, leading to significant losses of phosphate concentrate within the reject fractions [1].

2. Materials and Methods

The characterization of the waste materials rejected at the mine quarry was carried out by collecting representative samples from each phosphatic sub-layer. Chemical and mineralogical analyses were performed to determine the quality and composition of these waste materials, including Atomic Absorption Spectroscopy (AAS), X-ray diffraction analyses, and petrographic studies.

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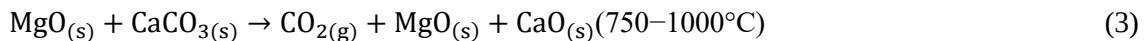
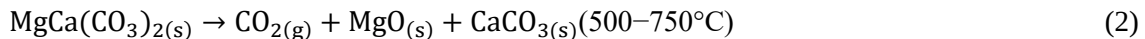


Fig. 1. The Kef Essenoun phosphatic deposit

Treatment tests were conducted on two phosphate mixtures: a mixture composed of the three beige phosphatic sub-layers and another mixture consisting of the two black phosphatic sub-layers. The beneficiation process was performed using a combined calcination–reverse flotation method [2].

Calcination was carried out in a muffle furnace at 1000°C for 15 minutes, followed by attrition washing using a magnetic stirrer.

The main chemical reactions occurring during calcination are represented by the following equations [3]:



The phosphate calcined at 1000°C was subsequently subjected to attrition washing using a magnetic agitator. The purpose of the attrition washing step was to reduce the MgO content according to the following reaction [3]:



The following table summarizes the operating conditions used during the reverse flotation experiments [2].

Table 1. Experimental Conditions for Reverse Flotation Tests

Parameters		Conditions
Pulp density		25%
Agitation speed		1200tr/min
Pulp conditioning time		3min
Conditioning time		10min
pH		9
	Collector: Oleic acid	2500g/t
	Activator: Ethanol	800g/t
	Depressant: Sodium potassium tartrate –	1200g/t
	pH regulator: Sodium hydroxide / phosphoric acid	-
	Frother: Sodium hydroxide	2000g/t

3. Results and Discussion

3.1. Petrographic Study

Microscopic observation of thin sections revealed that the five phosphatic sub-layers are mainly composed of coprolites, phosphate pellets, glauconite, and organic matter embedded within a dolomitic and calcitic matrix.

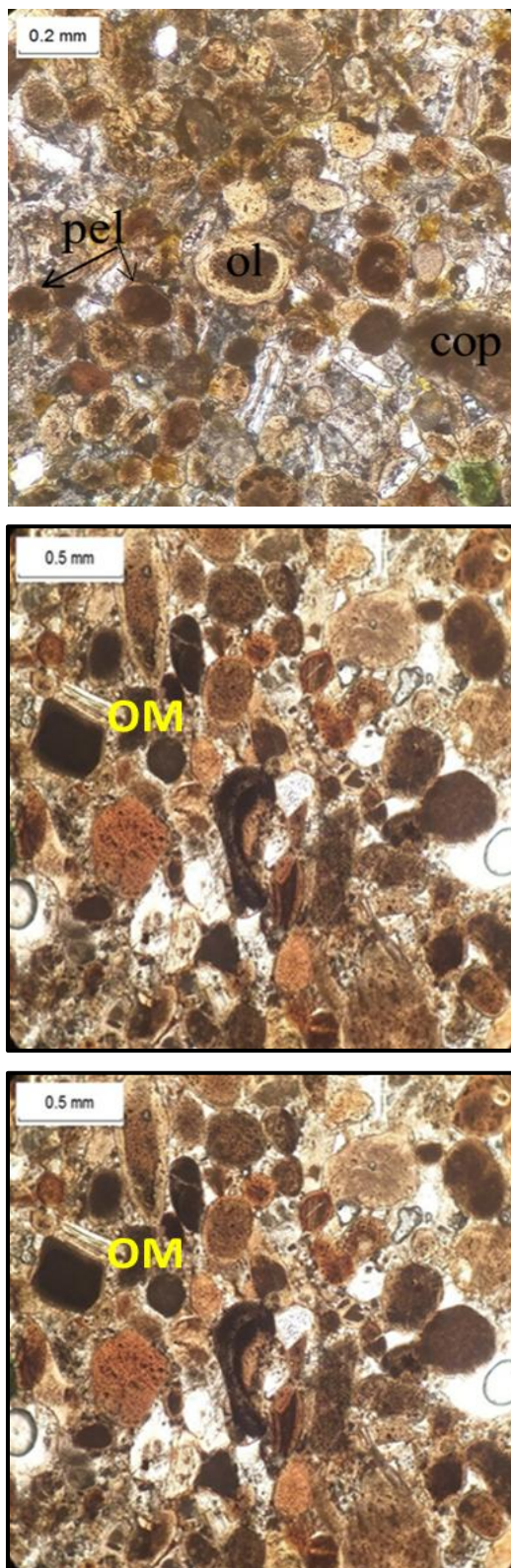


Fig. 2. Aspect of minerals observed in beige and black phosphate samples: (Cop) Coprolite; (Pel) Pellet; (Gl) Glauconite; (OM) Organic Matter.

3.2. Chemical Analysis

Chemical analyses of the samples collected from each rejected phosphatic sub-layer revealed significant enrichment in P_2O_5 content, with the following grades:

Table 2. Major Element Contents in the Different Phosphatic Sub-Layers

Beige phosphate				
Sample	Content, %			
	CO ₂	P ₂ O ₅	MgO	CaO
Lower sublayer	8.40	27.78	1.66	45.84
Main sublayer	8.40	27.91	1.39	46.05
Upper sublayer	20.08	18.44	4.48	30.43
Black phosphate				
Upper sublayer	18.40	19.57	4.64	32.29
Main sublayer	8.40	27.91	1.94	46.05

In this context, beneficiation tests were carried out using a mixture of the rejected beige sub-layers combined with the main layer, as well as a mixture of the upper and main black sub-layers.

The use of calcination allows the removal of organic matter and the decomposition of dolomite and calcite into MgO and CaO, respectively. This transformation facilitates their subsequent elimination through reverse flotation.

The results of calcination of the beige and black mixtures, separately, as well as the washing of the calcined products, are presented in the following table.

Table 3. Chemical Analysis Results of Calcined and Washed Beige and Black Phosphates

Samples	Content, (%)			
	P ₂ O ₅	MgO	CO ₂	CaO
Calcined beige phosphate	29.88	4.76	1.00	49.30
Calcined washed beige phosphate	30.12	2.98	1.49	49.70
Calcined black phosphate	27.28	7.49	1.16	45.01
Calcined washed black phosphate	27.39	4.63	1.63	45.19

3.3. X-ray Diffraction Analysis

X-ray diffraction (XRD) analysis of the calcined samples shows that the majority of the diffraction peaks observed in the beige and black phosphates correspond to phosphatic minerals, including fluorapatite, hydroxyapatite, and carbonate-fluorapatite.

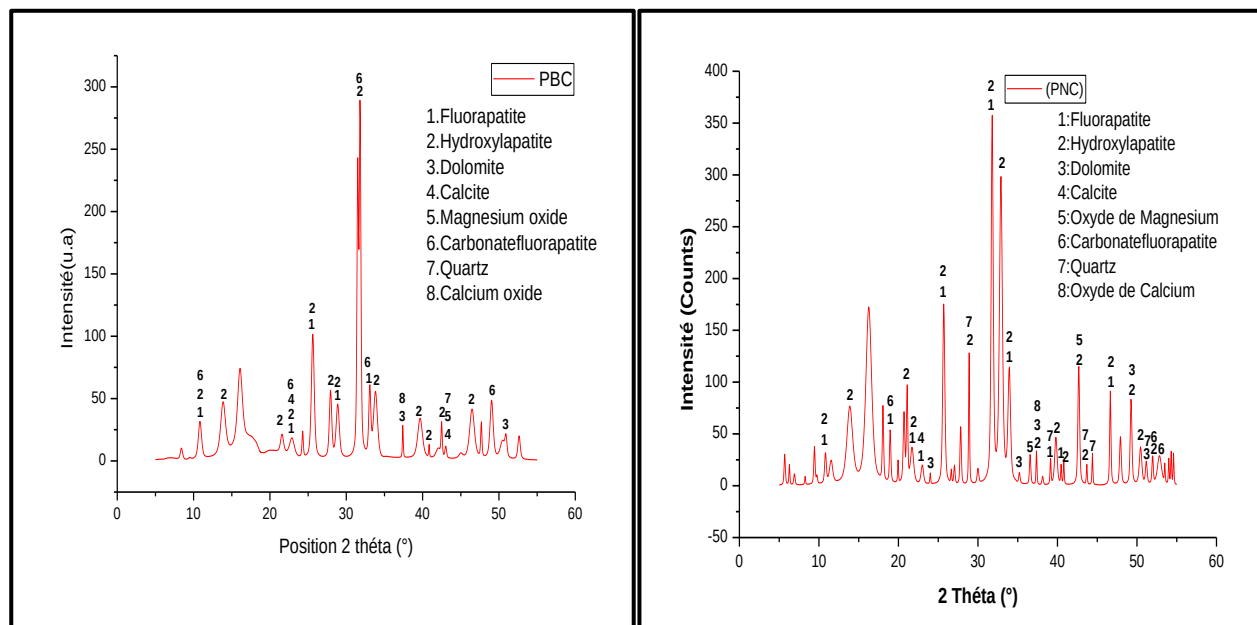


Fig. 3. X-ray Diffraction Results of Phosphate Calcination at 1000°C (Beige and Black)

Regarding gangue minerals, a weak presence of quartz peaks is observed, together with a significant reduction in dolomite phases. In addition, the appearance of CaO and MgO peaks is detected at $2\theta = 37.36^\circ$ and 42.91° , respectively.

The presence of CaO and MgO peaks confirms the thermal decomposition of calcium and magnesium carbonates into their respective oxides, accompanied by the release of carbon dioxide (CO₂).

3.4. Reverse Flotation

The results of the reverse flotation tests on the black and beige phosphates are presented in the following table.

Table 4. Chemical Analysis Results of Calcined floated Beige and Black Phosphates

Sample	Concentrate content (%)				Recovery (%)	
					Floated	Sink
Calcined Beige phosphate	P ₂ O ₅	MgO	Co ₂	CaO	2.07	97.93
	33.83	1.11	1.33	55.82		
Calcined Black phosphate	33.13	1.33	1.66	54.66	2.15	97.85

These results confirm that reverse flotation minimizes the recovery of gangue minerals in the concentrate while maximizing phosphate recovery, demonstrating the efficiency of the combined calcination–flotation process in upgrading phosphate ores.

4. Conclusions

Chemical analysis of the beige phosphates shows that the basal and main sub-layers are rich in P₂O₅, with contents of 27.78% and 27.91%, respectively, whereas the upper sub-layer exhibits a lower grade of 18.44%.

The P₂O₅ content in the mixture of the three beige sub-layers is 24.58%, with MgO and CO₂ contents of 2.98% and 12.05%, respectively.

For the black phosphates, the main sub-layer is also rich in P₂O₅ (27.91%), while the upper sub-layer is relatively poorer (19.57%). The blended black sample (two sub-layers) contains 23.51% P₂O₅, 3.48% MgO, and 13.05% CO₂.

Microscopic observation of thin sections shows that both beige and black phosphates are mainly composed of pellets, coprolites, and glauconite, with quartz, dolomite, and calcite acting as cementing gangue minerals.

X-ray diffraction analysis of both beige and black mixtures indicates that the main mineral phases belong to the apatite group (fluorapatite, hydroxyapatite, and carbonate-fluorapatite), while gangue minerals include quartz, dolomite, and calcite.

The use of calcination for both beige and black phosphates leads, on one hand, to the decomposition of dolomite and calcite into calcium oxide (CaO) and magnesium oxide (MgO), as confirmed by the appearance of MgO and CaO peaks in the XRD patterns. On the other hand, it improves the P₂O₅ grade, as confirmed by chemical analyses.

Attrition washing followed by desliming on a 63 µm sieve of the calcined products (beige and black, separately) proved effective in reducing the oxide content generated during calcination and in increasing the P₂O₅ grade.

Reverse flotation of beige and black phosphates, using proportional mixtures of washed calcined and washed raw materials, allowed a reduction in impurity content and an improvement in P₂O₅ concentration.

The overall results obtained from phosphate beneficiation using the combined calcination and reverse flotation method are promising, yielding P₂O₅ grades and recovery rates of 33.13% and 97.85% for black phosphate, and 33.83% and 97.93% for beige phosphate, respectively.

The use of chemical reagents in the reverse flotation process, such as fatty acids, alcohols, and alkaline regulators, may have potential environmental impacts if discharged without proper treatment. These reagents can contribute to an increase in the organic load of process water and may affect the quality of receiving ecosystems by altering pH and introducing residual flotation chemicals. In addition, the generation of fine tailings containing residual reagents may pose a risk of secondary contamination if not properly managed.

As a sustainable mitigation strategy, water recycling and reuse within the processing circuit represent an effective solution to reduce environmental impact. The implementation of closed-circuit water systems allows for the recovery of process water from tailings, thereby minimizing fresh water consumption and limiting the discharge of contaminated effluents. Furthermore, proper water treatment prior to reuse helps maintain the efficiency of flotation reagents while ensuring compliance with environmental standards. This approach significantly contributes to improving the overall sustainability of phosphate beneficiation operations.

Acknowledgements

We would like to express our sincere gratitude and appreciation to the staff of the Laboratory for the Valorization of Mineral Resources and Environment (LAVAMINE) for their valuable support and assistance throughout this work. We also extend our thanks to all those who contributed to this study, including the staff of SOMIPHOS for their collaboration and support.

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