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A Study on Apatite Recovering from the Tailing of the Bac Nhac Son-Vietnam Beneficiation Plant by Combined Flotation in Mechanical and Column Devices

Duoc Van Tran[1] · Son Hoang Nguyen[1] · Dung Thi Kim Nhu[1] · Thanh-Hai Pham[1]

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Abstract

Apatite ore plays a critical and irreplaceable role in fertilizer production and is being upgraded in quality in northern Vietnam. The old tailing of the Bac Nhac Son beneficiation plant (Vietnam) has a significant apatite amount in the form of coarse unliberated particles. These millions of tons of tailing ore have 6–8% of P_2O_5 content, which can be retreated to provide fertilizer factories. This work presents the results obtained in recovering apatite from this tailing in the laboratory. By the combination of the processes of classification, preliminary flotation, re-grinding and cleaning in the flotation column, an apatite concentrate of 30.68% P_2O_5 can be obtained with the total recovery of 37.76% from the initial tailing of 7.56% P_2O_5. The study results not only provide an appropriate technical solution for recovering the apatite ore from tailing ore but also have outstanding meaningness in the recovery of mineral resources under the context of a circular economy.

Keywords Apatite · Tailing · Column flotation · Re-grinding · Mechanical flotation

1 Introduction

The Bac Nhac Son beneficiation plant is one of the three main apatite beneficiation plants in Vietnam. The plant has been in operation since 2012 and annually process more than 1 million tons of ROM apatite ore to collect 350,000 tons of apatite concentrate to supply the fertilizer industry in Vietnam. After many years of operation in the plant tailing pond, a large volume of tailing has accumulated with content of 6–8% P_2O_5. As apatite ore reserves are increasingly depleted, the issue of recovering apatite from accumulated tailings is an urgent one. In the world there are some studies on recovering of apatite from old tailing [1–6]. Particle size analyses show that the tailing in the Bac Nhac Son beneficiation plant has a fineness of about 65-70% passing 0.074mm, and P_2O_5 content in the range of 6–8%. However, the fraction over 0.074mm has a content of up to 8–12% P_2O_5 and accounts for up to 60% of the P_2O_5 loss in the tailing. Preliminary mineral analyses also showed that the apatite component was mainly in the form of apatite-silicate interlocked particles. Experimental studies of apatite recovery from tailing by direct flotation without regrinding shows the poor results in both recovery and the concentrate grade. The regrinding of whole tailing is not economical option because there is a lot of coarse quarzt particles which are hard to grind. Then experimental studies of apatite recovery from tailing were conducted in the direction of size separation of fraction over 0.074mm and flotation of this fraction with conventional fatty acid collector allows for significant recovery of apatite. However, the quality of the concentrate obtained is still low, only reaching 22–23% P_2O_5 and has not reached the required quality as a raw material for fertilizer production. The reason is that the apatite component exists in the tailing mainly in the form of unlocked particle with waste rock minerals. In order to further improve the quality of apatite products, the preliminary flotation concentrate needs to be re-ground and refloated. Because the apatite ore in Lao Cai is in the weathering zone, the reground product contains many slimes that affect the flotation process. These ultrafine slimes always tend to entrained to froth product and degrade its quality. Column flotation is a non-traditional flotation device, but today has been widely applied in flotation practice [7–9]. One of the distinguishing features of column flotation equipment is that it allows maintaining a thick layer of froth and performing froth washing, which minimizes

✉ Thanh-Hai Pham
phamthanhhai@humg.edu.vn

1 Hanoi University of Mining and Geology, Hanoi, Vietnam

Table 1 Size composition of ore sample

Size fraction, mm	Wt, %	P_2O_5, %	Distribution, %
+ 0.2	10.56	13.42	18.75
+0.1–0.2	12.75	12.58	21.22
+0.074–0.04	14.82	3.75	7.35
+0.04–0.074	15.15	4.38	8.78
+0.02–0.04	12.16	5.87	9.44
+0.01–0.02	15.87	6.16	12.93
–0.01	18.69	8.71	21.55
Total	100	7.56	100.00

Table 2 Chemical composition of ore sample

P_2O_5, %	SiO_2, %	MgO, %	Al_2O_3, %	CaO, %	Fe_2O_3, %
7.56	62.56	1.76	7.17	12.56	3.75

Table 3 Mineralogical composition of ore sample

Minerals	Formula	Weight,%
Fluorapatite	$Ca_5(PO_4)3F$	18–20
Quartz	SiO_2	48–50
Illite (mica)	$KAl_2[AlSi_3O_{10}](OH)_2$	19–21
Kaolinite + chlorite		4–6
Hematite	Fe_2O_3	3–5
Other minerals (amphibol, boehmite)		Trace

entrainment phenomena and increases the quality of fine ore concentrates. Column flotation equipment also has low investment costs and not high operating costs [10–12]. The column flotation process, if it solves the problem of improving the quality of apatite concentrate recovered from the waste tailing, will open up the possibility of recovering apatite components in the tailing ponds, expanding the apatite ore resources and improving the economic efficiency of Vietnam apatite company as well as the whole fertilizer industry in Vietnam. In the new column flotation devices, the inclined plate flotation device (Reflux Flotation Cell) is a promising one [7–9, 13, 14]. In this article, we will present the results of the research on the flotation process to improve the quality of the apatite concentrate recovered from the tailing pond of the Bac Nhac Son - Lao Cai beneficiation plant on the laboratory inclined plate flotation equipment. The influence of several process parameters and equipment on flotation results was investigated.

2 Material and Experimental Method

2.1 Material

The sample of apatite tailing used in this study was taken from the tailing pond of the Bac Nhac Son beneficiation plant in Lao Cai province. The sample was subjected to particle size, chemical and mineralogical analysis. The particle size distribution of samples is analyzed by wet sieving analysis, and the P_2O_5 grade content of each size fraction was tested by atomic absorption spectroscopy (AAS). The standard method for the chemical composition and the mineralogical of research ore is analyzed by atomic absorption spectroscopy (AAS) and X-Ray diffraction. The result are shown in recpectively in Tables 1, 2, and 3.

2.2 Experimental Procedure

The test flowsheet is shown in Fig. 1. Firstly the fine fraction from the feed ore is separated by classification in hydrocyclone. The flotation is applied to the hydrocyclone underflow in order to remove the coarse quarzts particles which are hard to grind. The floated product then is washed, dewatered and ground to free the interlocked particles. The cleaning flotation is applied to the ground product to obtain the final apatite concentrate.

The hydrocyclone with diameter of 75mm and the Metso flotation machine D12 are used in respectively in the classification and preflotation tests. The column flotation is carried

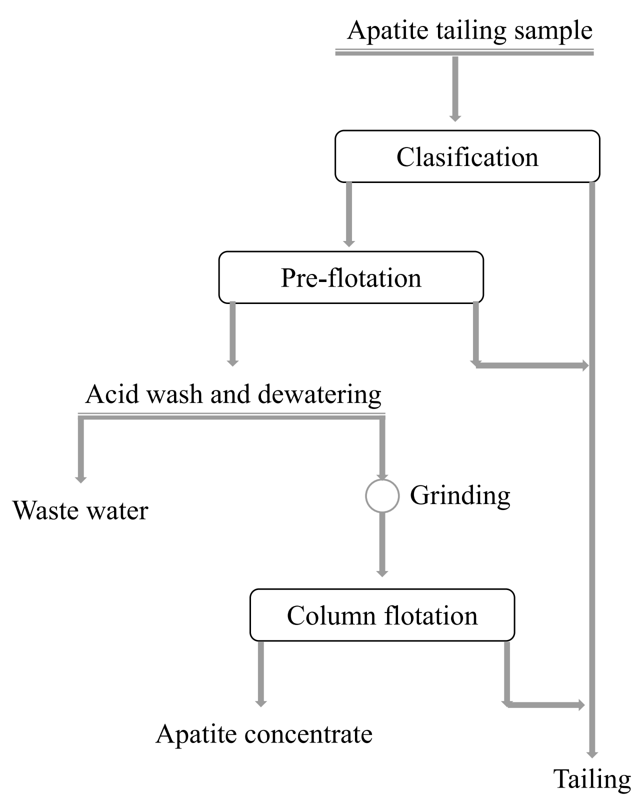

Fig. 1 The test flowsheet for apatite recovering from tailing

out in the device which is set up similarly to the reflux flotation cell. The schematic diagram of the test equipment is shown respectively in Fig. 2.

The test equipment [15, 16] is a two-part flotation column: the upper part is a cylinder of 10 cm in diameter and 1 m in length; the lower part is a 1 m long inclined parallelogram with the cross session of 10 × 10 cm and the tilt angle of 70°. In the parallelogram, the columns are installed the inclined plates. At the top of the column, there is a froth washing mechanism in the form of perforated cone. The flotation pulp is fed into the column tangentially at the bottom of the cylinder after mixing with the fine bubble from a perforated rubber tube in an aerator. The fine bubbles are also barbotaged at the bottom of the parallelogram box. The flotation froth, after passing through the washing zone, is discharged in the froth trough. The tailings pass the inclined channels and are removed by a discharge device in the form of a gooseneck tube. The level of the pulp (and the froth height respectively) can be controlled by choosing the suitable length of this tube. The concentrate and the tailing are discharged in separated containers. The pulp feed rate is adjusted by an inverter; the washing water flowrate—by a valve in the recirculated circuit.

3 Results and Discussion

3.1 Classification

From the particle size composition, it can be see that apatite tailing sample contains many fine particles of fraction passing 0.01 mm. This particle size fraction has a negative effect on flotation of coarser, especially over 0.074mm apatite-containing interlocked particles. Moreover, also from this granulometric composition, it is shown that the fraction +0.01–0.074mm has a lower P_2O_5 content. It is possible

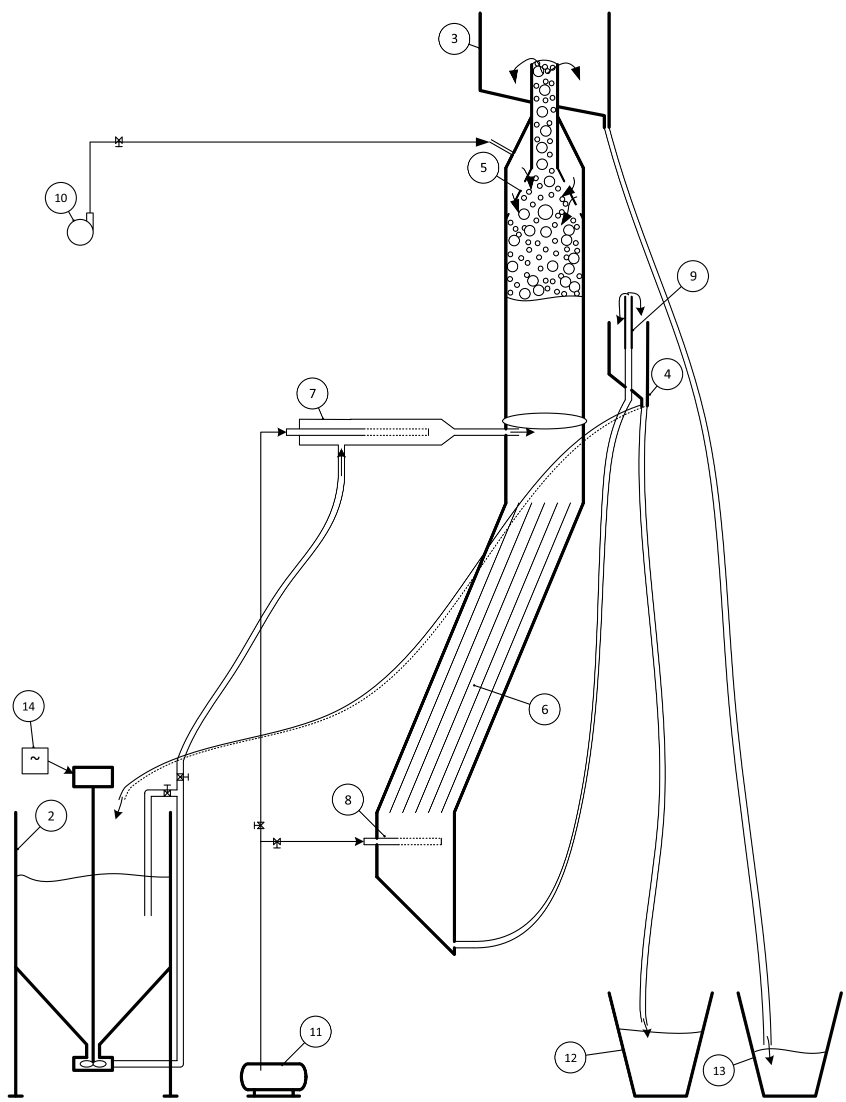

Fig. 2 The schematic diagram of the test flotation column in the type of reflux flotation cell [11, 12]

because the apatite particles in this fraction is well released and floats well at the plant. The classification process in the work was carried out to remove ultrafine particles as well as of the fraction of below 0.074 mm in order to reduce the mass of material to be ground and processed to reduce costs. The classification test was conducted using a 50mm diameter laboratory hydrocyclone to investigate the influence of some parameters on P_2O_5 recovery in the underflow product. The parameters investigated include pressure and solid content of feed as well as underflow discharge diameter. The optimal test conditions and results are presented in Fig. 3.

The results showed that by the classification, the underflow product with a content of up to 12.45% P_2O_5 with recovery of 63.81% was recovered, and a significant amount of fine particles with low P_2O_5 content were removed. This product needs further processing to meet the quality requirements.

3.2 Premilinary Flotation

The hydrocyclone underflow product (without further comminution) is upgraded on the preliminary flotation stage. Mineralogical analyses show that in hydrocyclone underflow, apatite exists in the form as interlocked with silicate minerals as well as coarse particles. At the same time in this product also contains many quartz particles that have been well liberated. This product could be ground directly and flotation afterward to recover apatite. However, the presence of coarse quartz particles will result in high comminution costs. It is therefore necessary to preliminarily flotation to remove coarse quartz particles to reduce the cost of grinding and subsequent cleaner flotation. The preliminary flotation test was carried out in the laboratory flotation machine Metso D12 using a collector in the form of a mixture of oleic acid with diesel oil. The reagent regime also includes the pH regulator NaOH, water-glass depressor, and eucalyptus oil frother BK201. Investigated the effect of many parameters on flotation results such as pulp density, dosages of pH regulator, depressor, collector and frother. Closed-circuit flotation test was carried out with one rougher and one cleaner. Optimal flotation conditions and flotation result are presented in Fig. 4.

The results showed that in the preliminary flotation process, apatite concentrate with a content of up to 23.50% P_2O_5 was obtained with a recovery of 77.92%.

3.3 Column Flotation

Column flotation is applied to reclean the preliminary flotation concentrate after its regrinding to improve the quality. The column flotation device is fitted with an inclined plate system to enhance the segregation of the liquid phase and gas phase and thus improve the efficiency of fine particle flotation. The reagent regime includes Azko Nobel's MD collector, NaOH pH modifier, water-glass depressor and BK201 frother. Investigated the influence of many parameters on flotation results such as equipment operation parameters (grinding fineness, pulp density, feed rate, froth thickness, washing water flowrate) as well as reagent regime parameters (dosages of pH regulator, collector, depressor, and frother). Closed-circuit column flotation test was carried out with one rougher and one cleaner. Optimal flotation conditions and column flotation test result are presented in Fig. 5.

The results showed that by column flotation, the P_2O_5 content in apatite concentrate was increased from 23.50% P_2O_5 to 30.68% P_2O_5 with recovery of up to 75.94%. Thus, from the initial apatite tailing with the content of 7.56% P_2O_5 through three stages of processing, namely hydrocyclone classification, preliminary flotation in mechanical machines and cleaning in column flotation, an apatite concentrate with a content of 30.68% P_2O_5 with total recovery of 37.76%.

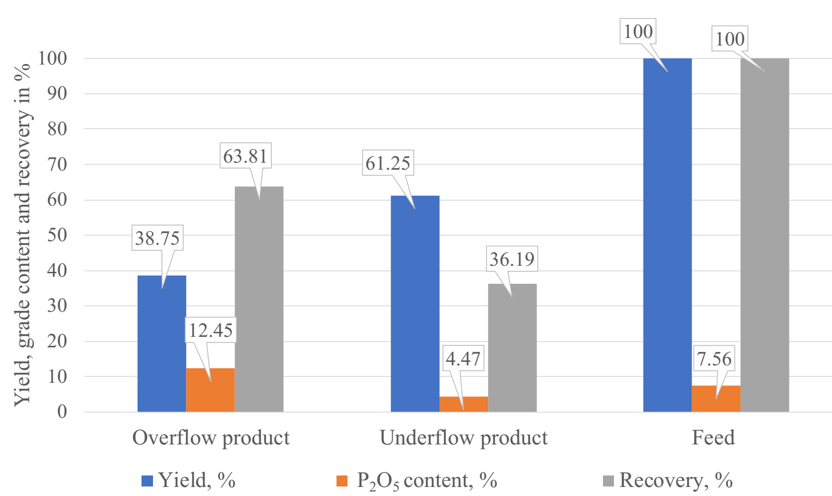

Fig. 3 Result of classification test by hydrocyclone. The test condition: feed pressure of 0.8 at feed solid content of 30%

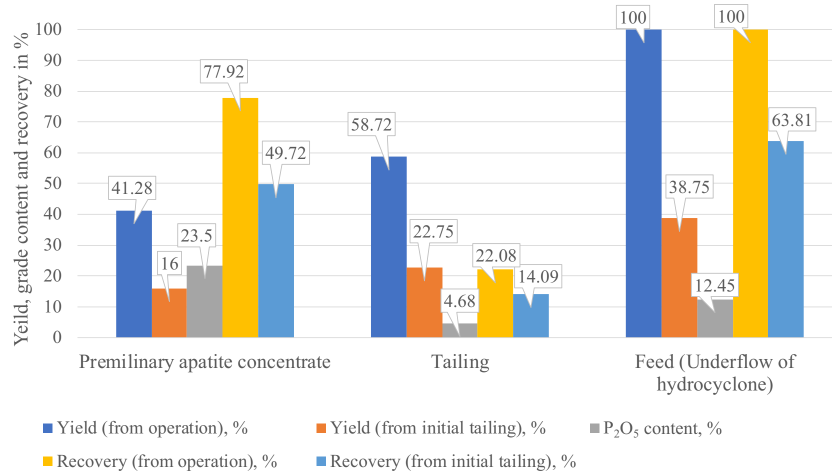

Fig. 4 Results of premilinary flotation test. The test condition: feed solid content of 40%; test flowsheet with 01 rougher and 01 cleaner; collector: mixture oleic acid + diesel oil ratio 1:1; collector dosage of 1.2kg/T; NaOH dosage of 0.2 kg/T; water-glass dosage of 0.3 kg/T

4 Conclusions

An investigation was conducted to develop an approach to recover apatite from an old tailing of Bac Nhac Son apatite beneficiation plant in Viet Nam. Hydrocyclone classification, flotation in mechanical, and in column machine have been carried out. Based on result obtained from the current work, the following conclusions are made:

- Apatite in tailing sample exists mainly as interlocked particles concentrated at coarse size fraction +0.074mm. In order to recover apatite into a high-quality concentrate, it is necessary to regrind and liberate apatite component before flotation. The orientation of classification and preliminary flotation before grinding and cleaning is to reduce grinding and processing costs;

- Removal of fine particle by hydrocyclone allows raising the P_2O_5 content to 12.5% with recovery over 63.81%. This process allows to significantly reduce the amount of ore going into subsequent stages of processing;

- Apatite-containing intercrystals in grade over 0.074mm in tailing can be recovered by flotation in traditional mechanical flotation machines with a collector in type of mixture of oleic acid with diesel oil. Preliminary flotation apatite concentrate with 23.50% P_2O_5 content and 77.92% recovery from 12.45% feed was obtained. The collector mixture dosage is 1.2 kg/t (oleic acid:diesel oil ratio is 1:1), the pH regulator NaOH dosage is 0.3 kg/t and the depressor water-glass dosage is 0.2 kg/T. The process flowsheet consists of one rougher stage followed by a cleaner flotation stage.

- By the process of re-grinding and column flotation, from the preliminary flotation concentrate, a final apatite concentrate with a content of 30.68% P_2O_5 can be obtained with a recovery of 75.74%. The chosen grinding fineness for the test is 90% passing 0.074mm. The MD collector dosage is 0.2 kg/t, the pH regulator NaOH dosage is 0.3 kg/t, and depressor water-glass dosage is 0.5 kg/T. The selection scheme consists of one rougher stage followed by a cleaner flotation stage.

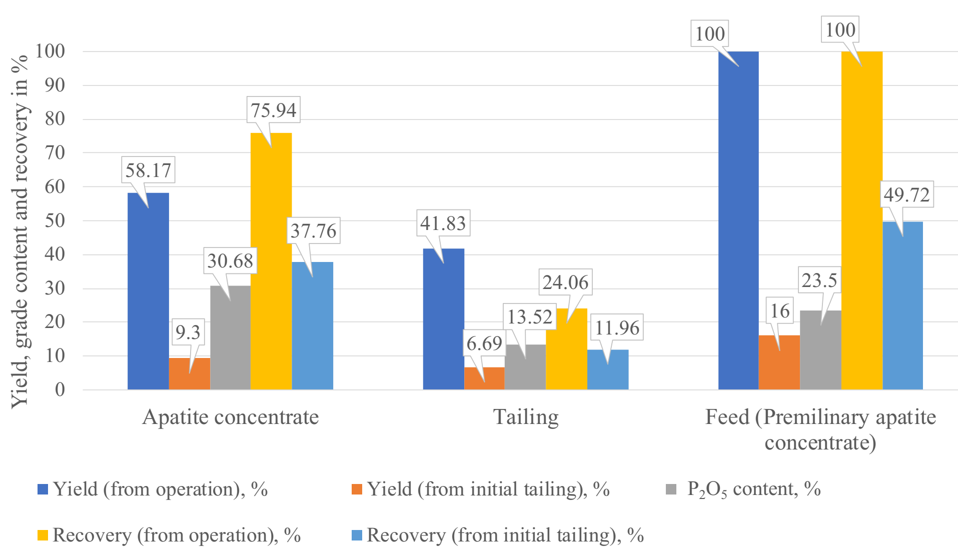

Fig. 5 Result of column flotation test. The test condition: test flowsheet with 01 rougher and 01 cleaner; grinding finess 90% passing 0.074mm; solid content of 15%; feed rate of 7L/min; froth thickness of 0.45m; washing water flowrate of 1L/min; collector (MD) dosage of 1.2kg/T; NaOH dosage of 0.2 kg/T; water-glass dosage of 0.3 kg/T; frother dosage of 0.1 kg/T

- From the initial tailing content of 7.56% P_2O_5 through processes of classification, preliminary flotation, re-grinding and cleaning in flotation column, an apatite concentrate of 30.68% P_2O_5 can be obtained with the total recovery of 37.76%.

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Declarations

Conflict of Interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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