Rational grinding circuit for siliceous apatite ore type III of Lao Cai Vietnam

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Abstract. Apatite ores type III of Lao Cai area, Vietnam is a class of weathered sileceous apatite ores, which may have most variable composition and primary slime content according to the weathering level and location. The three operating flotation plants use similar single-stage grinding circuits to process the highly weathered sileceous apatite ores and to achieve the concentrate grade requirement of 31% P2O5 with the aimed average recovery of about 70%. Single stage grinding circuits have worked well in the past as the designed criteria were achieved, however, mine production has increased sharply and deeper ores are being mined recently, so that the material composition of the run of mine ores have become more complicated and are the ores become more difficult to be floated. As a result, processing criteria of these plants become critically unstable and low. The study is to investigate the suitabity of two-stage grinding circuits for Lao Cai apatite ore type III. The report presents the results of the study on middlings regrinding of hard floatable apatite samples of Bac Nhac Son flotation plant, where high loss of valuable apatite has occured due to low grinding performance. Research results show that regrinding of all middlings to the fineness of 75% -0.04mm not only improves recovery but also help to stabilize technological operations and their processing criteria. The final concentrate grade of more than 31% P2O5, tailings content of less than 5% P2O5 and recovery of over 70% were achieved.

1. Introduction

Apatite is the main phosphate-baring mineral of the calcium phosphate group consisting of chlorapatite ($Ca_{10}(PO_4)_6(Cl)_2$), hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) and fluorapatite ($Ca_{10}(PO4)_6F$) [5]. It is used as the main raw material for the production of phosphorus and its compounds, which are widely used in the national economy. About 90% of the phosphorus demand goes to fertilizer industry while 10% remaining phosphorus demand goes to others such as metallurgy, chemical and paper industries, and animal feedstock [1; 2].

Vietnam apatite ore is a metamorphic sedimentary ore and it is classed into 4 basic types: Type I is the richest apatite ore of the weathered zones with P_2O_5 content of 28-37%; Type II is carbonaceous apatite ore of non-weathered zones with P_2O_5 content of 7-28%;

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Class III is siliceous apatite ore of weathered zones with P_2O_5 content of 9-25%; Type IV is a mixed carbonaceous – siliceous ore type of non-weathered zones with a P_2O_5 content of 4-15%.

All existing apatite ore flotation plants of Vietnam were designed to process weathered apatite ores type III containing quartz as the main gangue minerals and to some extend minor dolomite. The flowsheets of existing apatite flotation plants necessarily include two-stage crushing with primary crushed ore washing in rotary washing drums for slime removal; single stage grinding of finely crushed ores down to 70-80% of -0,074 mm size fraction in ball mills; desliming by a combination of hydrocyclones and thickeners; conditioning agitation and direct flotation in conventional mechanical flotation machines. For flotation of apatite, fatty acids are commonly used as collectors, Sodium silicate as depressant of quartz and caustic or ash soda for modifying of pH to 8-9 [4; 5; 6].

Flotation circuits of the existing apatite flotation plants of Vietnam necessarily include a rougher operation, 2-3 cleaning and 1-2 scavenger operations, which allow to achieve concentrate grade of approximately 31% P_2O_5, recovery of about 70%, and tailings P_2O_5 content of 5%. The plants have been operated smoothly until recent years, however, current ROM ore supply to the processing plants has become more and more volatile in terms of both grade, ore characteristics and mineral composition. The general technology, including comminution-separation flowsheets and operating regimes, gradually becomes more unsuitable due to these changes. As a result, unstable processing criteria and huge loss of valuable apatite have occurred. The P_2O_5 contents in tailings of the processing plants sometimes reached 8-9% [3]. In order to overcome this situation, it is necessary to have researches on technology improvement for comminution-separation flowsheets, grinding regimes, flotation operating regimes and even processing equipment etc.

2. Samples and methods of the study

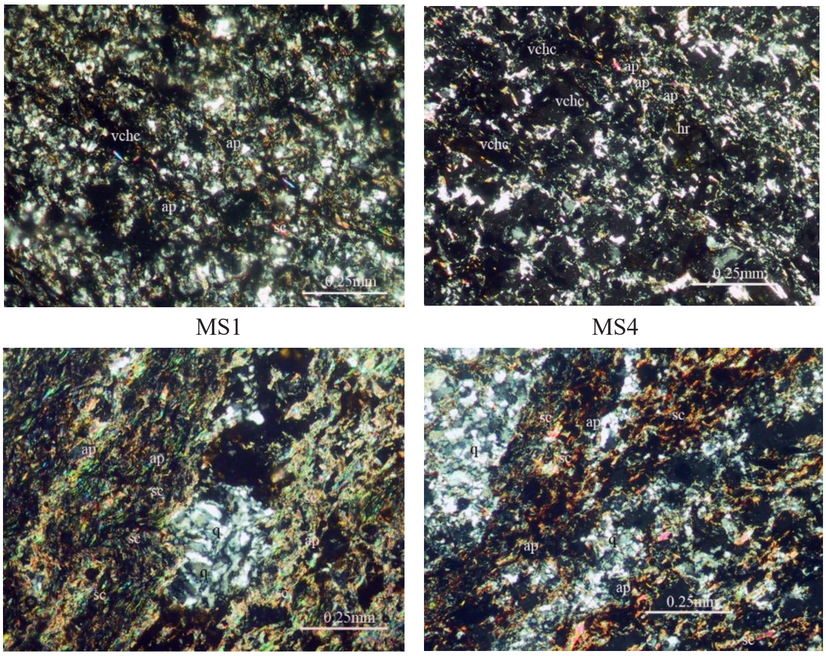
2.1 Samples

The study sample Q3 KT22, MC: 35 - 41, of 160-180 level, was collected from Bac Nhac Son (Lao Cai province) area of the most hardly floatable apatite ores type III. The amount of each sample taken to the laboratory was about 50kg, P_2O_5 content of samples MS1; MS4; MS5 and MS6 are about 8.5%; 18.5%; 13.5% and 17.5% respectively. The mineral composition of the samples is shown in Figure 1 and Table 1.

Table 1. The mineral composition of the samples

No	Mineral	Content, %			
		MS1	MS4	MS5	MS6
1	Clay, sericite, muscovite	27-30	20 - 22	63 - 64	35-37
2	Quartz	61-63	58 - 59	20 - 22	42- 45
3	Apatite	8-10	18 - 20	13 - 15	18-20
4	Iron hydroxide	1	1 - 2	1 - 2	1-2

The study samples consist mainly of apatite, quartz and clay minerals. Apatite mineral is in the form of microparticles and fine-grains. Fine grains of less than 0.01-0.05mm are either scattered or concentrated in group, in spots or thin strips stretched in a direction. Apatite is colorless, high floating with stainy surfaces and gray interference. The lowest grade MS1 sample contains over 60% quartz minerals, MS5 sample contains over 60% clay minerals.



MS1 MS4

MS5 MS6

Fig1. Study sample images under microsope

2.2 Methods of the study

The experiments were conducted by the traditional methods i.e serial experiments starting with the exploration of the most important parameters. In each serial test, all conditions were kept unchanged except the explored parameter. The best explored parameter's values of the previous experiment were used for the following series of experiments.

Most tests were conducted at the Laboratory of the HUMG Department of Mineral Processing using mechanical laboratory flotation machines with chamber capacities of 1-3l. The ore samples were crushed down to -3 mm size and then ground in a ball mill of 8l chamber capacity to the required mesh of grind before feeding to the flotation test.

The flotation products were filtered, dried, weighed and prepaired for the final analysis. The efficiencies of each experiment were assessed through a number of technological criteria including actual recovery in concentrate and P_2O_5 contents in both concentrate and tailings.

3. Results and discussions

3.1Conditional experiments

Series of conditional experiments of each ore sample were conducted according to the Figure 2 and the optimal operating regimes were determined as shown in Table 2 and the flotation results at optimal regimes are shown in Tables 3.

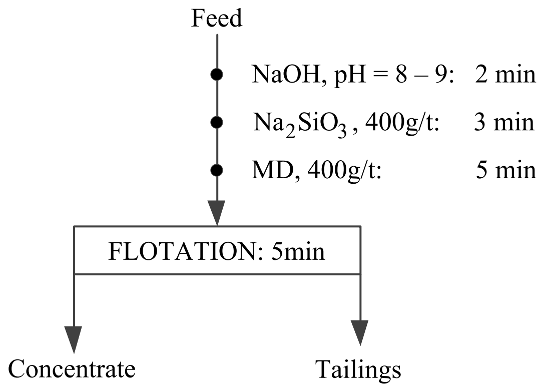


Fig 2. Conditional flotation test

Table 2. Optimal operating regimes of the samples

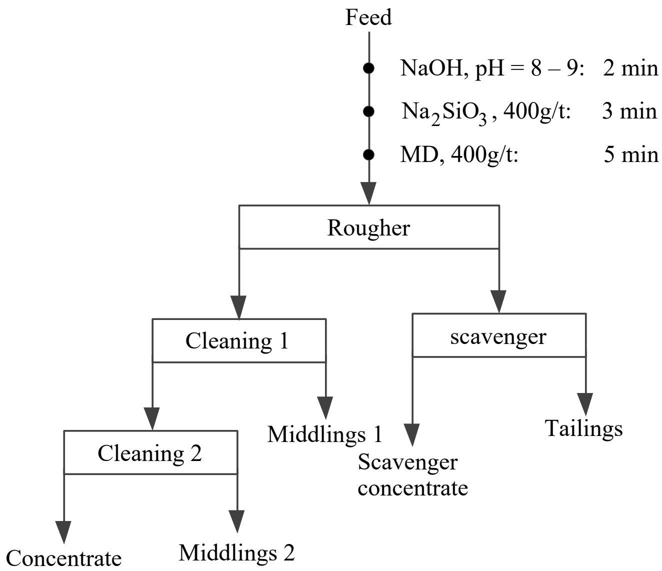
Operating variables/Sample	MS1	MS4	MS5	MS6
Mesh of grind, % of -0,074 mm	95.7	91.1	91.88	92.72
Solid concentration, g/l	300	300	300	300
NaOH dosage (pH = 8 - 9), g/t	800	800	800	800
Sodium silicate dosage, g/t	400	400	400	400
Collector MD, g/t	400	400	400	400

Table 3. Flotation results of the samples at optimal regimes

Sample	Product	Yield, %	P_2O_5 Content, %	P_2O_5 Recovery, %
MS1	Concentrate	50.24	15.72	93.13
	Tailings	49.76	1.17	6.87
	Feed	100	8.48	100
MS4	Concentrate	65.93	24.85	88.56
	Tailings	34.07	6.21	11.44
	Feed	100	18.5	100
MS5	Concentrate	58.99	20.03	87.78
	Tailings	41.01	4.01	12.22

	Feed	100	13.46	100
MS6	Concentrate	62.82	22.62	81.25
	Tailings	37.18	8.82	18.75
	Feed	100	17.49	100

From the experimental results, it can be seen that most of samples although of different mineral composition and P_2O_5 content, can be processed at similar flotation regimes; All samples require a grind fineness of over 90% of -0,074mm size fraction; Low grade ores (sample MS1) do not require scavenging operations as rougher tailings with P_2O_5 content of 1.17% are suitable for disposal.



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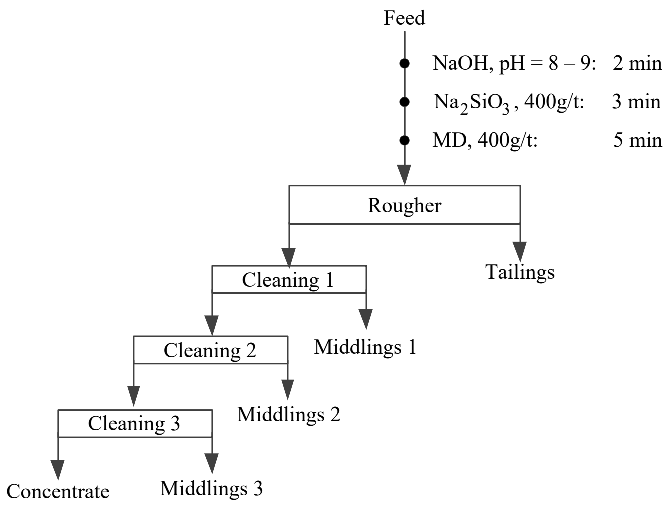

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Fig 3. Single stage flotation circuit tests

3.2 Single stage flotaion circuit selection

Purpose of the study is to determine suitable number of cleaning and scavenging operations for achivement of the desired concentrate grade and recovery. The study has determined optimal flotation open circuits for the ore samples MS4; MS5 and MS6 as shown in Figure 3a, while for MS1 sample as shown in Figure 3b. Flotation results according to the selected open circuits are shown in Table 4.

From the results of open circuit flotation test results, it is found that low grade ores (MS1) require 3 cleaning operations to achieve the desired concentrate grade but no scavenging operation due to very low P2O5 content in rougher tailings; Flotation middlings of higher grade ore samples, as shown on the Figure 3a, require further treatment due to their very high P2O5 content and low recovery into concentrate.

Table 4. Results of single stage flotation open circuits

Sample	**Product**	**Yield, %**	**P_2O_5 Content, %**	**P_2O_5 Recovery, %**
MS1	Concentrate	18.5	31.78	69.66
	Tailings	47.92	1.87	10.62
	Middlings 1	18.35	2.11	4.59
	Middlings 2	10.6	7.02	8.82
	Middlings 3	4.63	11.5	6.31
	Feed	**100**	**8.44**	**100**
MS4	Concentrate	35.59	33.28	63.78
	Tailings	26.08	4.37	6.14
	Scavenger concentrate	3.55	13.58	2.6
	Middlings 1	23.06	11.57	14.37
	Middlings 2	11.72	20.77	13.11
	Feed	**100**	**18.57**	**100**
MS5	Concentrate	33.16	29.15	71.87
	Tailings	35.13	2.42	6.32
	Scavenger concentrate	4.85	7.43	2.68
	Middlings 1	16.32	7.19	8.72
	Middlings 2	10.54	13.28	10.41
	Feed	**100**	**13.45**	**100**
MS6	Concentrate	38.12	31.21	68.21
	Tailings	31.28	5.48	9.83
	Scavenger concentrate	5.69	9.31	3.04

	Middlings 1	17.26	11.56	11.44
	Middlings 2	7.65	17.05	7.48
	Feed	**100**	**17.44**	**100**

3.3 Middling treatment selection experiments

Purpose of this study is to determine suitable middlings treatment flowsheets in order to maintain the desired concentrate grade and recovery with minimal loss of value to tailings. At the existing flotation plants, all middlings are returned to rougher operations for further recovery of values to concentrates. Returns of middlings to rougher operations not only increase circulating loads or pulp volumes but also cause rougher flotation disturbances leading to lower processing criteria such as lower concentrate grade and recovery. According to some previous studies, with hard-floatable apatite ore type 3, most middlings particles often are floated well at the rougher stage but badly floated at the cleaning stages due to the locking effect of values with gangue minerals [3]. Therefore, in this study, regrinding of middlings and different flotation circuits were subjects of considerations for improvement of the processing criteria.

Flotation circuit for both case with and without middlings grinding is shown in Figure 4 and results are given in Table 5. From experiments, it was determined that -0.04mm size fraction content in middlings before regrinding and after regrinding of middlings were of about 50% and 75% respectively.

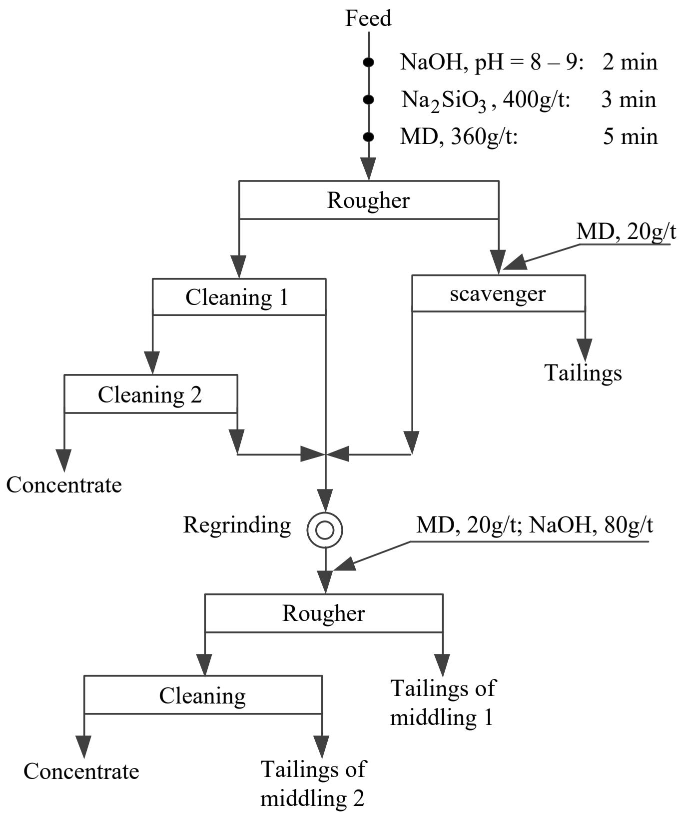

Fig 4. Two stage flotation circuit test

Experimental results in Table 5 show that regrinding of middlings improved the separation efficiency because of better apatite liberation: overall recovery of the samples MS4 and MS5 increased by 6%; and MS6 by 4% while concentrate grades were almost equivalent to conventional single stage flotation. However as per Table 5, high P_2O_5 contents in tailings of middlings flotation (tailings of middlings 1 and 2 in Figure 4), especially high in tailings of the rich samples MS4 and MS6, were due to absence of scavenging flotation of these tailings. This indicates that actual middlings flotation circuits should include a scavenging operation and a return of cleaning tailings to the rougher operation.

Table 5. Flotation results with and without middlings regrinding

Sample	Product	Without regrinding of middlings			With regrinding of middlings		
		Yield, %	**% P_2O_5**	**Recovery, %**	**Yield, %**	**% P_2O_5**	**Recovery, %**
MS4	Concentrate	35.58	33.27	64.19	35.05	33.42	63.35
	Middlings concentrate	1.65	26.77	2.4	6.17	27.73	9.25
	Total of concentrate	**37.23**	**32.98**	**66.59**	**41.22**	**32.57**	**72.6**

	Tailings	26.82	4.74	6.89	26.52	4.66	6.68
	Tailings of middling 1	8.2	10.58	4.7	20.94	11.17	12.65
	Tailings of middlings 2	27.75	14.5	21.82	11.32	13.18	8.07
	Feed	**100**	**18.44**	**100**	**100**	**18.49**	**100**
MS5	Concentrate	27.97	32.57	68.49	28.04	32.61	67.29
	Middlings concentrate	3.11	27.45	6.42	7.3	26.55	14.26
	Total of concentrate	**31.08**	**32.06**	**74.91**	**35.34**	**31.36**	**81.55**
	Tailings	36.77	2.49	6.88	36.13	2.47	6.57
	Tailings of middling 1	27.66	7.63	15.87	22.73	5.28	8.83
	Tailings of middlings 2	4.49	6.92	2.34	5.8	7.15	3.05
	Feed	**100**	**13.3**	**100**	**100**	**13.59**	**100**
MS6	Concentrate	34.61	32.05	62.78	34.73	32.05	62.71
	Middlings concentrate	0.52	25.86	0.76	3.49	25.12	4.94
	Total of concentrate	**35.13**	**31.96**	**63.54**	**38.22**	**31.42**	**67.65**
	Tailings	32.02	5.27	9.55	31.9	5.26	9.45
	Tailings of middling 1	23.89	14.18	19.17	22.3	13.1	16.46
	Tailings of middlings 2	8.96	15.26	7.74	7.58	15.07	6.44
	Feed	**100**	**17.67**	**100**	**100**	**17.75**	**100**

Conclusions

From the study results of some hard-floatable apatite ore type III from Bac Nhac Son area, Lao Cai, some conclusions can be made as the followings:

1. Mineral composition of apatite ore type III samples of Bac Nhac Son area includes apatite, quartz, clays, sericite. However, apatite is finely disseminated in quartz that is the main cause of low efficiency;
2. Lowgrade ores such as MS1, it should be floated in open-circuits in order to obtain concentrate of the required quality, middlings and tailings can be disposed without retreatment;
3. Recovery of flotation circuits with middlings regrinding generally increase recovery of P_2O_5 to above 72% while overall concentrate grade . So it is obvious that middlings regrinding of finely disseminated and high grade ores is more rational. Middlings regrinding and its floation may give more stable processing criteria due to absense of rougher operation disturbances, lower circulating loads and assured

flotation time. Besides, two stage grinding remarkedly reduces slime generation and reduce energy consumption compare to the existing single stage grinding;

4. It is necessary to continue studying on optimizing mesh of grind of grinding stages and middlings flotation circuits in order to reduce energy consumption, to improve the processing criteria. Further studies should develops most suitable flowsheets and floation regimes for hardly floatable apatite ores type III for coping with recent changes in the ROM ore supply to processing plants.

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