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An Overview of Rare Earth Ores Beneficiation in Vietnam

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Abstract. Rare earth metals are used in electricity, electronics, nuclear, optics, space, metallurgy, superconducting and super magnetic materials, glass and ceramics, and agriculture. Some rare earth elements are added to fertilizers for crops and some trials for animal feed. Rare earth elements, except for radioactive promethium, are relatively abundant in the earth's crust. Vietnam has a tremendous rare earth potential, distributed mainly in the Northwest, including Nam Xe, Dong Pao, Muong Hum, and Yen Bai. There are many research projects on rare earth ores of different types globally, but the focus is mainly on the essential minerals, including monazite, xenotime, and bastnaesite. This report summarizes research data on rare earth ore intending to produce a general assessment of rare earth ore and its beneficiation technology in Vietnam.

Keywords: Rare earth, Monazite, Xenotime, Bastnaesite

1. Introduction

Rare earth is the common name for a group of rare metallic elements or rare earth metals, including 17 chemical elements of Mendeleev's periodic table such as scandium, yttrium, and 15 elements of the Lanthanide group, which have a relatively large percentage in the earth's crust. Nowadays, about 250 minerals containing rare earth elements have been discovered in the earth's crust. About 1/2 have been identified in mineral lattice structures, and more than 60 minerals contain not less than 5,0 - 8.0% REO. It is noteworthy that there are six different ore minerals processed in the industrial productions, which include bastnaesite [$(Ce,La)(CO_3)F$], monazite [$(Ce,La)PO_4$)], xenotime (YPO_4), loparite [$(Ce,Na,Ca)(Ti,Nb)O_3$], apatite [$(Ca,REE,Sr,Na,K)_3Ca_2(PO_4)_3(F,OH)$], and ion-adsorption clays [1-3]. The first three minerals, known as the commercial rare earth elements (REE) mineral sources, contribute to almost 95% of the world's reserves: bastnaesite (70–75% rare earth oxides REO), monazite (55–60% REO), and xenotime (55-60% REO). The mainly exploited rare earth minerals of industrial values are bastnaesite, monazite, xenotime, and gadolinite, which bastnaesite occupies one-third of the world's rare earth production. Recently, rare earth in clays with ionic adsorption has been found in the weathered laterite crust [4-7].

Rare earth elements (REEs) are classified into two groups, "heavy" and "light", depending on the density of their atom. "Light" REEs include lanthanum (La) (number 57 in the periodic table) to europium (Eu) (number 63 in the periodic table). In contrast, 'heavy' REEs include gadolinium (Gd) (64) to lutecium (Lu) (71), and yttrium.

The common rare earth minerals in nature are shown in Table 1.

Tab. 1. The common rare earth minerals in nature [11-13].

No	Minerals	Chemical formula	Distribution of main rare earths	The grade of REO; %
I - Phosphate group				
1	Monazite	$(Ce,La,Th).(PO_4,SiO_4)$	Light group	60.6
2	Apatite	$(Ca,Ce)_5.(PO_4)_3.(F,Cl)$	Light group	0-5
3	Xenotime	YPO_4	Heavy group	61.4
4	Flurenxite	$(Y,Al_3).(PO_4)_2.(OH)_6$	Heavy group	32
5	Rapdofanite	$(Ce,Y).PO_4.H_2O$	Light group	36-65
II - Carbonate and Fluor carbonate group				
6	Bastnaesite	$(Ce,La).CO_3.\ F_2$	Light group	74.77

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7	Pazisite	$CaCe_2.(CO_3)_3.F_2$	Light group	60.89
III – Oxide group				
8	Loparite	$(Ce,Ca, Na).(Ti,Nb)O_3$	Light group	16-19
9	Fecgusonite	$(Y,Er,Ce,U,Th,...).(Nb,Ta,Ti).O_4$	Heavy group Light group	54 3
10	Samacskite	$(Y,Er,Ce,U,...)_4.(Nb,Ta)_6.O_{21}$	Heavy group Light group	9.13-27.86 1.36-9.11
11	Euxenite	$(Y,Ce,Ca,U,Th).(Nb,Ta,Ti)_2O_6$	Heavy group Light group	16-27.8 0.4-3.5
12	Priorite	$(Y,Er,Ca,U,Th).(Nb,Ti)_2.O_6$	Heavy group Light group	21.1-28.7 3.7-4.3
13	Branerite	$(U,Ca,Y,Fe, Th)_3.Ti_2O_{16}$	Heavy group	3.9
14	Conopite	$(Ce,Ca).(Ti,Fe).O_3$	Light group	7
15	Piroclo	$(Na,Ca,Ce,Y,\ldots)_2.(Nb,Ti,\ldots)_2.O_6.(F,OH)_7$	Heavy group Light group	5 2 - 13.3
IV – Silicate group				
16	Gadolinite	$(Ca,Y)_2.Fe.(Be_2Si_2O_{10})$	Heavy group	55.4
17	Eudialite	$(Ce,Y,Ca)_4.(Fe,Zr).(Si_8O_{18}).(OH,Cl)$	Light group	0.3-2.9
18	Xerite	$(Ce,Ca)_{10}.(SiO_4)_6.(OH,F)$	Light group	50
19	Orthite (Allanite)	$(Ca,Ce,Y).(Mg,Al)_2.[(Si_2O_7).(SiO_4).(O,OH)]$	Heavy group Light group	18 8
20	Rincolite (Lopchorite)	$(Ca,Na,Ce)_3.(Ti,Nb).(SiO_4)_2.(F.OH)_2$	Light group	13-20
V – Fluorine group				
21	Fluxerite	$(Ca,Y).F_3$	Heavy group	70

In recent years, an increase in demand for REEs has been observed because of their unique properties and various applications. By the mid-twentieth century, rare earth materials were only used in the military field. Since 1987, their use has expanded to include glass, ceramics, catalysts in the oil refining and metallurgical industries. Over time, less than 5% of rare earth production was used in the electronics industry to produce high-strength magnets. Nowadays, with the high development of the metallurgical industry, rare earth alloy products are widely used in many sectors, such as the food industry, healthcare, ceramics, computers, color television screens, and environmentally friendly cars, magnets, batteries, petrochemical catalysts, rockets, radar, etc. [8-10].

2. Mining and processing of rare earth in Vietnam

2.1 Rare earth mining

Vietnam is one of the countries possessing rare earth resources. As a result of research and exploration works carried out since 1958, many rare earth deposits have been discovered in Nam Xe North, Nam Xe South, Dong Pao (Lai Chau), Muong Hum (Lao Cai), and Yen Phu (Yen Bai).

Placer REEs are mainly monazite, xenotime, a kind of rare earth phosphates, while silicate REEs (orthites) are less common. In the mainland and coastal areas, REEs are distributed in the river and stream shelves, such as REEs mines in the Bu Khang North region (Nghe An). In this area, small mines are in Pom Lau - Ban Tam, Chau Binh, and Ban Gio, with the monazite grade accounts for 0.15-4.8 kg/m^3, and simple mining and processing conditions are applied. There should be evaluation for further exploration and exploitation when a need appears. In the coastal areas, many active mines and ilmenite placer deposits contain rare earth minerals (monazite, xenotime) with concentrations from 0.45-4.8 kg/m^3, such as Ky Ninh, Ky Khang, Cam Hoa, Cam Thuong (Ha Tinh), Ke Sung (Hue), Cat Khanh (Binh Dinh), Ham Tan (Binh Thuan) mines, etc. However, to date, REEs in those mines have not been fully evaluated [13-15].

Despite the tremendous rare earth potential of the country, rare earth mining in Vietnam is almost small-scale, and processing technology is still outdated. The mining method is mainly manual. Consequently, large resource losses (up to 60%) and disadvantages are low capacities and incapability for completely separating REEs. Besides environmental problems, it would be no value added of REEs if Vietnam cannot process raw materials.

Each year, Vietnam only mines a few tens of tons of bastnaesite ores from Dong Pao mine and a few thousand tons of monazite ores with a grade of 35-45% REO from the central coastal placer mines for limited sale by quota. Dong Pao rare earth mine, Tam Duong district (Lai Chau), is the largest rare earth mine in Vietnam at the moment, with a total area of more than 11 km^2, reserves of over 5 million tons of oxides. The main ore bodies are F3 and F7, which contain REEs suitable for electronic factories. The Dong Pao mine project is an open-pit type of surface mining utilizing a sequence of mining, mineral processing, and hydrometallurgy for treating 1,088,000 tons capacity of the run of mine ores in the future [16,17].

It is necessary to prevent pollution from the first stage of project investment and pollution control from the first step of the project's operation to exploit REEs efficiently, protecting the environment and safety. Along with the excavation of rare earth mines such as Dong Pao, Nam Xe, etc. it is necessary to continue to invest in discovering and fully evaluating this precious mineral in other regions of Vietnam.

2.2 Research on beneficiation of rare earth ores in Vietnam

Until now, all rare earth ore processing technologies in Vietnam have remained mainly laboratory-scale and semi-industrial-scale research projects, with almost no significant applications in industrial production scale. Based on semi-industrial scale tests, several studies on ore processing technology of Nam Xe South, Dong Pao, Yen Phu mines, some marine placer deposits, and several processing flowsheets have been proposed. There is the suggestion that the research results can be applied to production. However, currently, only some research results on monazite recovery from marine placers have been applied. The research in the field of hydrometallurgy and extraction is still limited due to not insufficient data and conditions to evaluate the capability and economic efficiency.

2.2.1 Dong Pao rare earth ores

The Dong Pao rare earth ore is a type of "multi-metallic" complex ore that is very difficult to beneficiate. The total rare earth oxide grade is not high at 5.98% REO. The ore has relatively high barite and fluorite grades which are of 21.58% $BaSO_4$ and 12.35% CaF_2 respectively. Many other minerals are associated with rare earth, such as Ca, Al, Fe, Si, S, Mn, Pb, Mg, etc. Rare earth minerals exist mainly in the form of bastnaesite. Barite minerals account for the largest percentage in quantity as well as the content. In addition, a few REEs exist in the form $(Ca,Y)F_{2-3}$ - Yttrofluorite, and fluorite exists in the form $CaF_2.[(CaF_2)_{0.75}(YF_3)_{0.25}]$ [13].

The Dong Pao rare earth ore processing tests were conducted in 1986 to explore and excavate the mining area between Vietnam and Germany. The test flowsheet is shown in Figure 1, and the results are shown in Table 2 [18].

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Tab. 2. Results of direct flotation of Dong Pao rare earth ore.

Stage	Product	Yield, %	Grade, %			Recovery, %		
			REO	$BaSO_4$	CaF_2	REO	$BaSO_4$	CaF_2
	Feed	100.00	11.25	49.53	10.44	100.00	100.00	100.00
Grinding, screening	Rare earth concentrate I (1)	13.62	38.09	14.71	4.12	46.37	4.07	5.40
	Particle size +0.03 mm	86.38	6.99	55.05	11.44	53.63	95.93	94.60
Flotation	Concentrate $BaSO_4$ (7)	51.79	0.77	86.50	1.65	3.54	90.44	8.19
	Tailings CaF_2 (8)	7.66	15.60	7.45	5.04	10.53	1.14	3.66
	Concentrate CaF_2 (9)	15.88	13.58	5.00	39.10	49.18	1.60	59.48
	Rare earth concentrate (10)	11.95	20.74	12.3	21.90	20.38	2.75	23.27
	Rare earth concentrate (1) + (10)	24.47	30.34	13.65	12.10	66.75	6.82	28.67

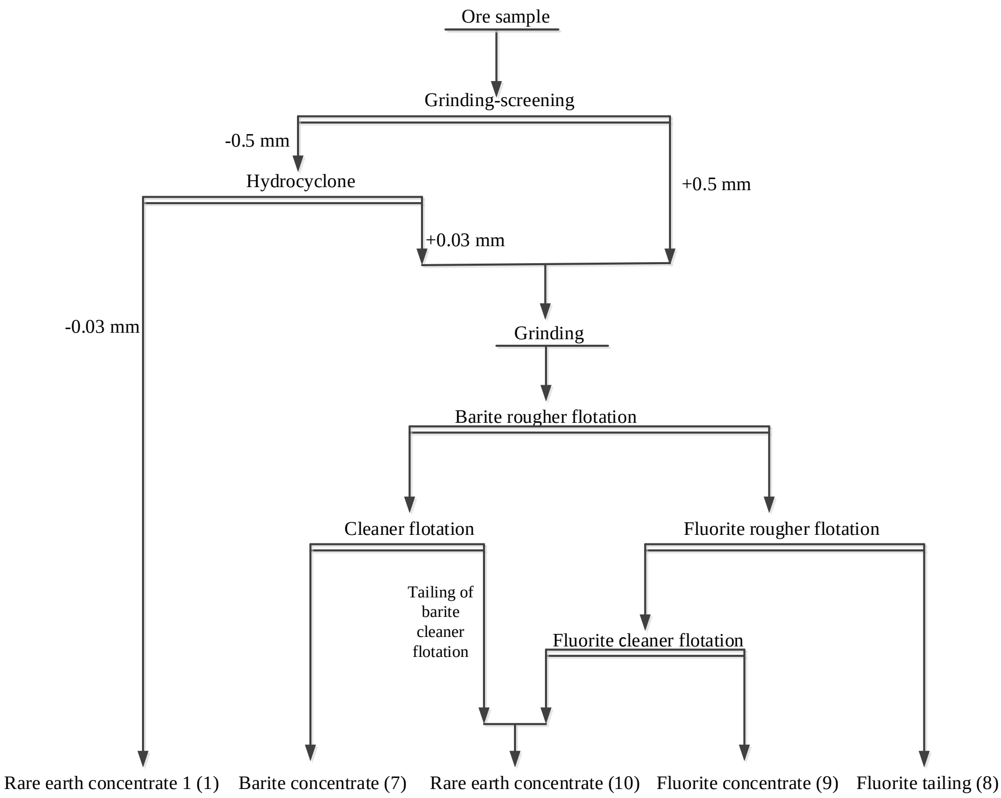

Fig. 1. Flotation flowsheet of the Dong Pao rare earth ore in research cooperation with Germany.

The Dong Pao rare earth ore sample was sent to Lakefield Research Laboratory in Ontario, Canada, for further flotation studying. Preliminary research has been conducted on three different processing flowsheets: Direct flotation REO from the feed ore, CaF_2 - $BaSO_4$ - REO selective flotation, and $BaSO_4$ - CaF_2 - REO selective flotation. REO direct flotation flowsheet, similar to bastnaesite treatment flowsheet of Mountain Pass flotation plant. The results of direct flotation REO and selective flotation CaF_2 - $BaSO_4$ - REO, respectively, are shown in Tables 3-4, indicating that these two flowsheets are not adequate for the concentrates of $BaSO_4$, CaF_2, REO separately.

The selective flotation flowsheet of $BaSO_4$ - CaF_2 - REO respectively is much more efficient because barite has a good float ability. The criteria of the separate concentrates are also higher than the other two flowsheets. The processing flowsheet and results are shown in Tables 5-6. However, all the results obtained, the concentrates of REO did not exceed 40%, and the highest recovery obtained less than 70% [18, 19].

Tab. 3. The result of rare earth direct flotation from the feed.

Products	Yield, %	Grade, %			Recovery, %		
		CaF_2	$BaSO_4$	REO	CaF_2	$BaSO_4$	REO
Test 1							
Concentrate REO of the third cleaner flotation	33.63	6.50	38.60	6.76	49.10	21.20	45.40
Concentrate REO of the firstcleaner flotation	62.06	5.82	54.20	5.96	81.10	54.90	73.90
Concentrate REO of rougher flotation	87.89	5.03	58.60	5.58	99.40	84.20	98.00
Tailings REO of rougher flotation	12.11	0.21	80.00	0.81	0.60	15.80	2.00
Feed ore (calculated)	100.00	4.45	61.20	5.00	100.00	100.00	100.00

Tab. 4. The result of CaF_2 - $BaSO_4$ - REO selective flotation.

Products	Yield, %	Grade, %			Recovery, %		
		CaF_2	$BaSO_4$	REO	CaF_2	$BaSO_4$	REO
Test 2							
Concentrate CaF_2 of the third cleaner flotation	15.33	7.63	79.70	2.39	25.90	18.80	5.70
Concentrate CaF_2 of the second cleaner flotation	16.94	7.24	79.30	2.61	27.20	2.07	6.90
Concentrate $BaSO_4$ of the third cleaner flotation	55.54	3.29	86.20	1.34	40.50	74.00	11.70
Concentrate $BaSO_4$ of the second cleaner flotation	58.64	3.61	82.89	2.14	47.00	74.90	19.70
Concentrate REO of the third cleaner flotation	10.73	8.40	23.40	34.30	20.00	3.90	57.60
Concentrate REO of rougher flotation	13.42	8.41	20.00	30.90	25.00	4.10	65.00
Tailings REO of rougher flotation	11.00	0.35	1.40	4.89	0.90	0.20	8.40
Feed ore (calculated)	100.00	4.51	64.90	6.39	100.00	100.00	100.00

Tab. 5. The result of $BaSO_4$ - CaF_2 - REO selective flotation.

Products	Yield, %	Grade, %			Recovery, %		
		CaF_2	$BaSO_4$	REO	CaF_2	$BaSO_4$	REO
Concentrate $BaSO_4$ of the fourth cleaner flotation	58.70	0.06	97.10	0.55	1.60	85.20	5.10
Concentrate$BaSO_4$ of the third cleaner flotation	62.88	0.09	96.20	0.82	2.50	90.40	8.20
Concentrate CaF_2 of the third cleaner flotation	9.47	11.20	42.20	4.48	49.10	6.00	6.70
Concentrate CaF_2 of the second cleaner flotation	10.96	10.60	41.70	5.57	53.80	6.80	9.60
Concentrate REO of cleaner flotation	13.88	6.26	11.70	30.60	40.20	2.40	67.10
Concentrate REO of rougher flotation	19.50	4.69	9.01	25.00	42.40	2.60	76.90
Tailings REO of rougher flotation	6.66	0.41	1.28	4.97	1.30	0.10	5.20
Feed ore (calculated)	100.00	2.60	66.90	6.33	100.00	100.00	100.00

Dong Pao rare earth ore samples were studied and concentrated by Sumitomo Metal Mining Company (Japan) using a flotation flowsheet to separate barite - fluorite - rare earth; the experimental results are shown in Table 7. The results show that obtained rare earth concentrates reached a grade of 45.9-48.4% REO. The recovery is in the range of 75.6-76.1% [20].

Nguyen Van Hanh (2005) studied the separation of rare earth, fluorite, and barite from weathered ores of Dong Pao mine and concluded that the main mineral of Dong Pao rare earth ores is bastnaesite. From his works, the ore samples, containing an average of 8-10% REO, were selectively ground and then cleaned by hydraulic classification and magnetic separation. A concentrate of 31.77% REO at a recovery of 84.46% on a laboratory and semi-industrial scale can be produced. Besides, the study determined the ability to separate barite and fluorite by flotation with reagents such as fatty acids and alkyl sulfates [15].

Tab. 6. The results of $BaSO_4$ - CaF_2 - REO selective flotation of the F3 and F4 ore bodies of the Dong Pao rare earth mine.

Samples	Products	Yield, %	Grade, %			Recovery, %		
			$BaSO_4$	CaF_2	REO	$BaSO_4$	CaF_2	REO
F3	Concentrate $BaSO_4$ of the third cleaner flotation	27.52	84.20	3.33	2.94	90.80	3.20	4.80
	Concentrate $BaSO_4$ of the second cleaner flotation	31.83	73.80	9.95	7.60	92.10	10.90	8.10
	Concentrate CaF_2 of the third cleaner flotation	17.34	1.23	82.30	10.70	0.80	49.30	11.00
	Concentrate REO of the third cleaner flotation	31.20	3.22	30.10	32.70	3.90	32.40	60.30
	Concentrate REO of the second cleaner flotation	39.56	3.58	27.80	32.20	5.50	38.00	75.20
	Concentrate REO of rougher flotation	45.87	3.63	24.90	29.50	6.50	39.50	79.90
	Tailings REO of rougher flotation	4.95	2.59	1.60	3.35	0.50	0.30	1.00
	Feed ore (calculated)	100.00	25.50	28.90	16.90	100.00	100.00	100.00
F4	Concentrate $BaSO_4$ of the third cleaner flotation	27.83	74.40	2.33	2.21	92.00	3.70	4.00
	Concentrate $BaSO_4$ of the second cleaner flotation	35.41	59.40	4.80	11.50	93.50	9.70	8.80
	Concentrate CaF_2 of the third cleaner flotation	15.90	1.33	47.80	21.00	0.90	43.50	21.80
	Concentrate REO of the third cleaner flotation	30.25	1.62	22.40	28.40	2.20	38.80	56.20
	Concentrate REO of the second cleaner flotation	36.65	1.77	20.50	26.90	2.90	42.90	64.40
	Concentrate REO of rougher flotation	37.81	1.82	19.90	26.50	3.10	43.00	65.50
	Tailings REO of rougher flotation	10.88	5.15	6.08	5.43	2.50	3.80	3.90
	Feed ore (calculated)	100.00	22.50	17.50	15.30	100.00	100.00	100.00

Duong Van Su (2010) mentioned a combination of magnetic separation and flotation circuit to separate Dong Pao rare earth ores. The REEs content increased from 8.7% REO up to 31.66% REO at a recovery of 63.52%. However, this research has not recovered barite and fluorite minerals from the F7 orebody of the Dong Pao mine [13].

2.2.2 Nam Xe North rare earth ores

There are two main types of ores at the Nam Xe North mine, the weathered and the lode ores; thus, the technological samples here should be studied accordingly in two directions. The rare earth mineral is bastnaesite, with a relatively small mineral content of 5-7%. Non-ore mineral composition accounts for the main proportion, including barite, quartz, illite, kaolinite, feldspar, goethite, chlorite...

In 1971, the Institute of the Nonferrous Metallurgy studied the weathered ores from the Nam Xe North mine. An ore sample at 14.8% REO was taken and tested. The sample was tested in two alternative magnetic separation and flotation circuits. The magnetic separation circuit increased the magnetic concentrate by 19.5 % REO. The flotation circuit consisted of a rougher and five cleaners, obtained a concentrate of 18.5% REO [21].

In 2013, the National Institute of Mining - Metallurgy Science and Technology studied the technological experiment of rare earth ore extraction at Nam Xe North rare earth mine. The technological sample has chemical compositions as follows: 4.6% REO, 19.63% $BaSO_4$, 0.15% CaF_2, 21.8% SiO_2, 15.31% Fe. The research has used the flotation method to recover rare earth concentrate and barite concentrate. The results are as follows: The obtained rare-earth concentrate ore has more than 30% REO content, corresponding to the total recovery of 59.40%. In addition, barite concentrate with $BaSO_4$ content of more than 95% was also obtained, equivalent to a total recovery of 63.56%. The tailings contain about 2% REO, corresponding to a rare earth recovery of about 35.90% [21].

2.2.3 Nam Xe South rare earth ores

Fong-Sam (2013) reported proven reserves at Nam Xe South to be 199,300 tonnes of REO and probable reserves to be 3.0 Mt of REO [22]. REE concentrations reported for the Nam Xe South carbonatites are as follows: TREE from 3,400 ppm to 6,100 ppm in calciocarbonatites, and from 43,200 ppm to 163,900 ppm in ferrocarbonatites, respectively [23, 24]. Detailed mineralogical studies [25] revealed that parisite $Ca(REE)_2[CO_3]_3(F,OH)_2$ is the main REE-bearing mineral in the ores of Nam Xe South. Other rare earth fluoro-carbonates, such as bastnaesite $(REE)[CO_3](F,OH)$ and synchysite $Ca(REE)(CO_3)_2(OH,F)$ occur only in minor amounts. The ore contains considerable amounts of baryte celestine, i.e., minerals of the baryte-celestine solid solution series [26], calcite, biotite, and magnetite. Especially the barytocelestine is finely intergrown with parisite on a sub-100µm-scale [25].

The results of the beneficiation research on Nam Xe South rare-earth were as follows: The mineral composition of Nam Xe South rare earth ores is complex with fine dissemination and intimately associated barite, calcite, mica, magnetite, quartz. The raw ore of grade 7 - 10% REO was ground and directly floated with sodium, NaF, dextrin, liquid glass according to Mountrin Pass's circuit to produce a rare-earth concentration containing 30 - 35% REO, at a recovery of 80 - 85%. In addition, the study had recovered barite by flotation separation. The barite concentrate grading of 85% $BaSO_4$ was obtained at a recovery of 54%. However, the content of rare earths in barite concentrate is still quite high, up to about 7% REO. A principal flowsheet is shown in Figure 2 [27, 28].

Robert Möckel et al. (2019) has studied the flotation of Nam Xe South rare earth ore. Flotation tests were redesigned with a two-step rougher flotation and a scavenger where the concentrate is re-feed into the wet milling followed by a wet re-grind of the rougher concentrate to minus 40 µm feeding into a 3 step cleaner flotation with a scavenger of the first cleaner tailing. The more sterile scavenger concentrate is re-feed into the regrinding stage before the cleaners. TREO concentrate grades of more than 40 wt% could be reached in the cleaner stage. The most effective way turned out to be a combination of cold (rougher) flotation on de-slimed ore at a coarser grain size (-100 µm) and a subsequent hot (cleaner) flotation after regrinding down to minus 40 µm. The REE loss of the de-sliming procedures was found to be below 8%. In contrast to the initial liberation evaluation, the regrinding step needed a better grade than 35% REO [29].

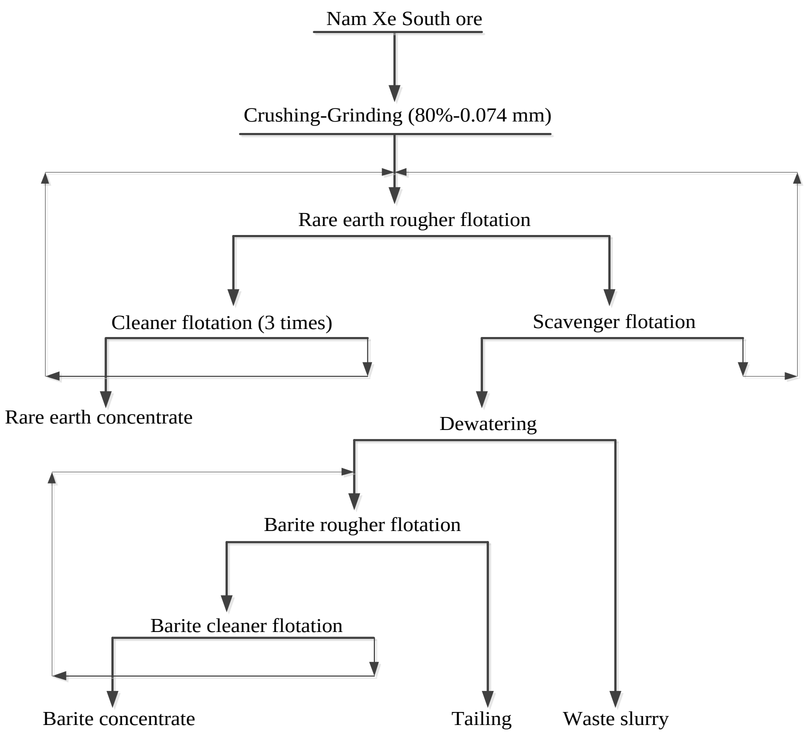

Fig. 2. Experimental flotation flowsheet for Nam Xe South rare earth ores.

2.2.4 Yen Phu rare earth ores

The Yen Phu rare earth mine has a reserve of about 28,000 tons of REO. Rare earth minerals are xenotime in small content. Iron minerals include goethite and magnetite, which account for 18-20% and 24-26%, respectively. Other components include mainly quartz 41-43%, kaolinite + chlorite 3-5%, feldspar 2-4%, talc 1-3%, etc. The ore has an average content of ~ 1.2% REO, ~33% Fe, ~40% SiO_2, etc [30]. Yen Phu rare earth mine is the primary one of Vietnam to implement both mining and processing of rare earth ores. After more than two years of operation (since 2019), the achieved processing performance is low with the rare earth recovery of less than 50% REO, the average tailings are about 0.7% REO. The processing flowsheet of the plant includes a combination of gravity concentration- magnetic separation - flotation. Gravity separation uses the washing–classifying process. There are three stages of magnetic separation to recover iron concentrate of the desired grade. Flotation recovering rare earth minerals includes 01 rougher, 03 cleaner, and three scavenger flotation. Chemicals used include soda ash (pH = 9); water glass, lignin, corn starch as depressants; Berol and diesel oil as a collector. An outline of the flowsheet is shown in Figure 3 [31].

3. Conclusions

Vietnam's rare earth resources are relatively large. However, the application of REEs so far is still minimal and currently mainly stands at laboratory-scale or semi-industrial studies. Rare earth mining and processing in the country is still very modest.

Many research has concentrated on separating rare earth ores with different ore types, focusing mainly on the most critical minerals of bastnaesite, monazite, and xenotime.

The methods for extraction and recovery of minerals in rare earth ores are mainly combinations of gravity concentration, magnetic separation, electrostatic separation, and flotation. Flotation is the only method in the beneficiation flowsheets of Nam Xe North and Nam Xe South ores. For Dong Pao and Yen Phu ores, combinations of gravity-magnetic separation -flotation methods are used.

There should be further studies of technological processes and proper equipment for each rare earth ore type to maximize resource recovery, improve economic efficiency, and protect the environment in Vietnam and worldwide.

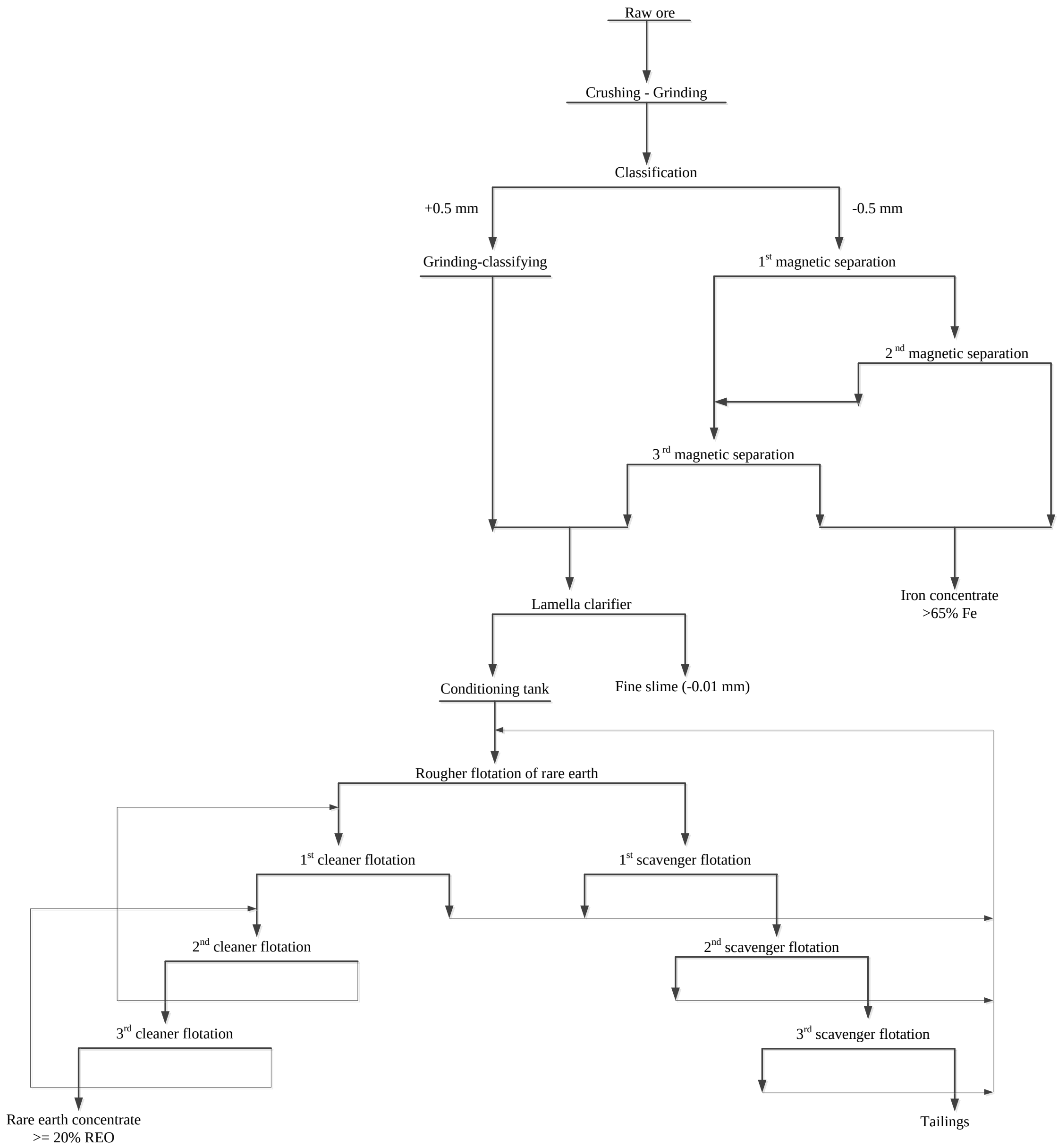

Fig. 3. Outline flowsheet of the Yen Phu rare earth ores in 2020.

4. Acknowledgments

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5. References

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