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Purification and Characterization of Monazite from Bangka using Mechanical-Magnetic Separation Method

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Abstract: In this research, the purification and characteristics of monazite, a by-product of the tin ore enrichment process. Monazite is given pre-treatment to monazite sand using the mechanical-magnetic separation method to increase the content of rare earth metal elements. Based on the results of the analysis of monazite samples from Tin mine tailings concentrate that has been purified, the dominant elements of the highest rare earth metals are cerium (Ce), lanthanum (La), neodymium (Nd), and Yttrium (Y). The mechanical-magnetic separation method, monazite from Tin mine tailings concentrate can have higher purity. These rare earth metal elements can be further extracted or synthesized; and used as supporting or even main materials in developing advanced technological industries.

Keywords: Element composition; Mechanical-magnetic separation; Microstructure; Monazite; Rare earth

Introduction

Over the past ten years, there has been a huge increase in interest in the beneficiation of rare earth elements (REE) minerals. The demand for REEs has surged due to the various industrial and technological applications of REEs, including microwave communications, electric vehicles, wind turbines, lasers, navigation and control, and rechargeable batteries (Abaka-Wood et al., 2024; Chung et al., 2020; Haider et al., 2021; Omodara et al., 2019).

Monazite is an economically valuable mineral that is a by-product of the industrial-scale tin ore enrichment process on Bangka Island (Indriawati et al., 2020; Subagja, 2018; Sumarni et al., 2011). Monazite sand is one of the main sources of commercial minerals such as thorium and rare earth metal elements which are generally associated in the form of orthophosphate ((Ce, La,Th)PO_4) crystals so that they have high chemical and thermal stability (Abdel-Rehim, 2002; Borai et al., 2017; Demol et al., 2024). The relatively high content of rare earth elements, which quantitatively depends on the area of origin of the sand, makes monazite sand a strategic mineral in extracting rare earth elements (Kumari et al., 2015).

Monazite is a monoclinic light rare earth element (LREE) phosphate mineral [(LREE) PO_4]. Ni et al. (1995) and Clavier et al. (2011) presented a thorough explanation of the structure and crystal chemistry of monazite. Although monazite-(La), monazite-(Nd), and monazite-(Sm) are also known, cerium dominating monazite (monazite-(Ce)) is the most frequent. Monazite structure most favorably integrates LREEs from La to Nd (Zi et al., 2024).

Monazite sand is an associated mineral and in nature is not found in abundant amounts localized in an area like other mineral ores so the mining process is very dependent on the capacity of the main mineral ore enrichment process (Belova, 2017). Although recently alternative waste-based sources of rare earth metal

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elements have been discovered, including nuclear material waste, but their content is relatively low compared to natural monazite mineral ore (Abdel-Rehim, 2002; Borai et al., 2017). Therefore, an effective and efficient method is needed in the process of extracting rare earth metals from monazite sand so that it can increase the resulting yield capacity.

State Various extraction methods have been developed in order to increase the yield of rare earth metal elements including using chemical methods: acid digestion, alkaline digestion, chloronization and physical: carbon-based high-temperature reduction, ion exchange systems, and so on (Belova, 2017; Berry et al., 2018; Borai et al., 2017; Indriawati et al., 2020; Kumari et al., 2015; Merritt, 1990b, 1990a; Omodara et al., 2019). Initial information regarding the characteristics of monazite sand, including elemental composition, phase, morphology, and particle size distribution, is very important to know and is key in determining the efficiency and effectiveness of the extraction method used (Anitha et al., 2020; Tranvik et al., 2017; Udayakumar et al., 2020). This data is the main basis for planning optimization parameters that will be used in each rare earth element extraction process. In this research, an analysis has been carried out regarding the characteristics of monazite sand originating from the industrial-scale tin ore enrichment process on Bangka Island, including the composition and distribution of elements in the morphology and phases of monazite sand. Apart from that, pre-treatment has also been carried out on monazite sand using the mechanical-magnetic separation method in order to increase the content of rare earth metal elements which will be used as precursor minerals in the extraction of rare earth metal elements.

Method

Monazite sand, a by-product of Tin ore refining originating from Bangka Island, is washed using water to remove impurities such as soil and organic compounds and then dried using an oven (100°C for 60 minutes). Next, mechanical-magnetic separation is carried out, where this process uses a gravimetric method to remove the dark-colored sand, then uses a neodymium magnet to separate the magnetic minerals in the monazite sand. At the end of this stage, two parts are produced, namely light-colored sand, which will later become a precursor, and dark-colored sand, which is an impurity mineral. The two parts of the sand are then crushed and sifted using a 325 mesh (44 microns) to obtain a homogeneous powder. The stages of this research are briefly visualized in Figure 1.

Next procedure, mass reduction is calculated for each process, and determination is carried out: elemental composition using X-ray Fluorescence type PANalytical Epsilon 3, phase composition using X-ray diffraction type X'Pert PRO PANalitycal MPD PW3040 /60, distribution of elements on the surface structure using Scanning Electron Microscopy - Energy Dispersive Spectroscopy type Thermoscientific Quanta 650, and particle size using Particle Size Analyzer type Horiba SZ-100 on monazite sand and its impurities.

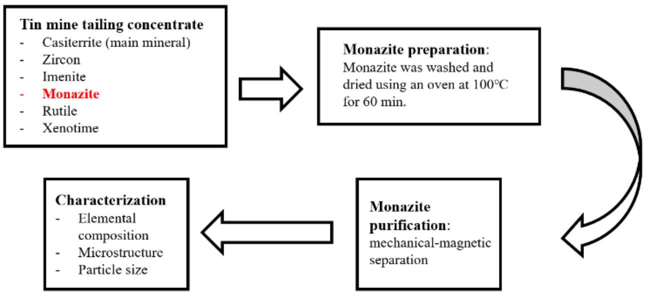

Figure 1. Research scheme for monazite purification

Result and Discussion

Preparation and purification

Magnetic separation is a process of separating minerals by exploiting differences in their magnetic properties (Jordens et al., 2014; Roy et al., 2020; Yu et al., 2017). Monazite is a mineral that does not have electrical properties (non-conductor) but has magnetic properties. The monazite mineral will respond to magnetic fields (Sajima et al., 2020). Figure 2 shows very contrasting differences in physical appearance and color appearance. This means that Tin mine tailings concentrated on monazite still have other minerals attached because, before the magnetic separation process, we carried out a mechanical process, namely grinding the monazite. For the percentage of mass reduced in the purification process, we use two stages, namely water washing (10.56%) and mechanical-magnetic separation (31.45%).

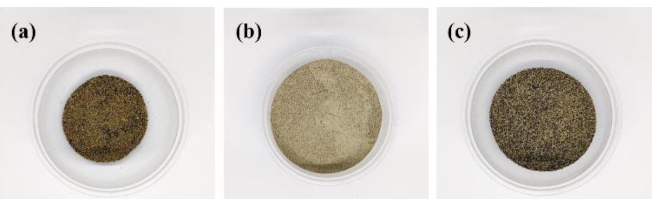

Figure 2. Photo of the physical appearance of monazite before and after the purification process: (a) natural monazite from Bangka [MZ #1], (b) product from mechanical-magnetical separation [MZ #2], and (c) impurities from mechanical-magnetical separation [MZ #3].

Elemental composition dan microstructure

The elemental composition of monazite was analyzed using XRF and SEM-EDS (Nuchdang et al., 2021; Okeme et al., 2021; Rejith et al., 2022). XRF is a method used to analyze elements and the weight percentage of unknown minerals (at the stage of purifying minerals directly from nature or by-products of mineralogical processes). The elemental composition was also analyzed by mapping the morphology using SEM-EDS to confirm further (Durdziński et al., 2015; Han et al., 2022; Ramirez-Leal et al., 2014).

Table 1. The element composition of monazite before and after the purification process based on the results of XPS characterization

Element	Content (% Wt)	Element	Content (% Wt)
MZ #1			
Ce	26.46	Th	7.49
Nd	11.76	Sn	6.25
La	10.86	P	5.93
Y	9.81	U	0.47
Fe	8.93	Others	12.04
MZ #2			
Ce	32.42	P	6.97
La	15.53	Sn	6.06
Nd	11.46	Y	4.72
Th	7.12	Others	15.72
MZ #3			
Ce	22.36	La	8.39
Y	16.98	P	6.88
Fe	12.92	Th	5.78
Nd	10.12	Others	16.57

Table 1 shows that the elemental composition of monazite before and after the purification process has elements that are representative of monazite in general. With the purification process, the main elements of monazite are increased, although not all. This is because there are still main elements in monazite that are attached and carried away by impurity (MZ #3) (Bora et al., 2021; Machado et al., 2006; Mahdy et al., 2020; Shahbaz, 2022).

Furthermore, in further characterization of elemental composition, Figure 3 shows monazite's morphology or surface shape before and after the purification process. It can be seen that Figures 3(a) and 3(c) have the same morphology, especially in the areas that are snapshots of spectrum 1, 2, and 3. However, in Figure 3(b), the morphology shown is quite clear because the impurities of the elements in monazite have been separated.

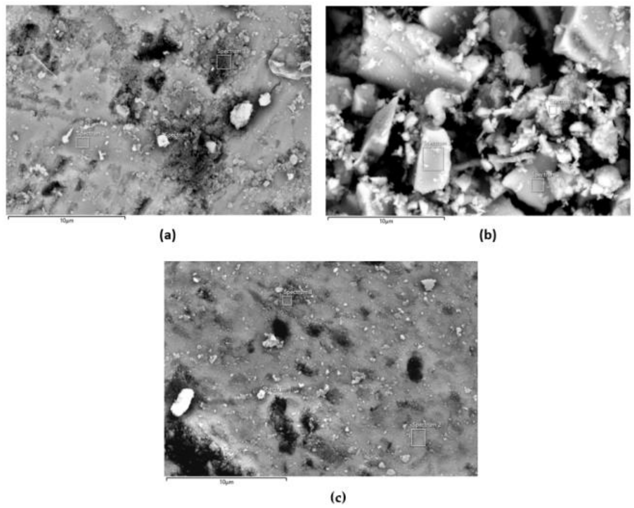

Figure 3. The element distribution on the morphology of: (a) natural monazite from Bangka; (b) product from mechanical-magnetic separation; and (c) impurities from mechanical-magnetic separation.

Table 2. The distribution of elements on the morphology results from SEM-EDS characterization

Spectrum 1		Spectrum 2		Spectrum 3	
Element	Content (% Wt)	Element	Content (% Wt)	Element	Content (% Wt)
MZ #1					
O	22.72	Ce	29.62	O	27.91
Fe	21.02	O	20.89	Ce	22.18
S	19.20	La	13.36	La	10.72
C	18.06	P	12.18	C	8.25
Ce	8.43	Nd	10.61	P	7.56
La	3.79	C	7.44	Fe	6.95
Others	6.78	Others	5.90	Others	16.43
MZ #2					
O	32.21	Ce	31.02	Ce	33.44
Ce	24.46	La	15.92	O	16.09
P	11.43	O	15.24	La	15.59
La	9.99	Nd	11.79	Nd	13.71
Nd	8.54	P	11.66	P	11.74
Others	13.37	Others	24.37	Others	9.43
MZ #3					
O	40.08	O	38.81	O	37.51
Y	30.26	Ce	25.56	Y	33.20
P	13.15	Y	15.92	P	14.25
Ce	9.23	P	12.11	Ce	8.75
Others	7.28	Others	7.60	Others	6.29

To observe the morphology of monazite further, we also analyzed the distribution of its elemental composition using EDS based on its concentration weight. Table 2 shows the results of SEM-EDS characterization by taking three snapshots and displaying them in spectra 1, 2, and 3. All samples show that the elemental analysis in spectra 1 and 3 is less representative due to inconsistencies in the percentage weight of several monazite elements from the XRF results, namely Ce, La, and Nd. Meanwhile, spectrum 2 has a consistent concentration weight. Thus, this monazite sample can be further tested to determine its microstructure using XRD and its particle size using PSA.

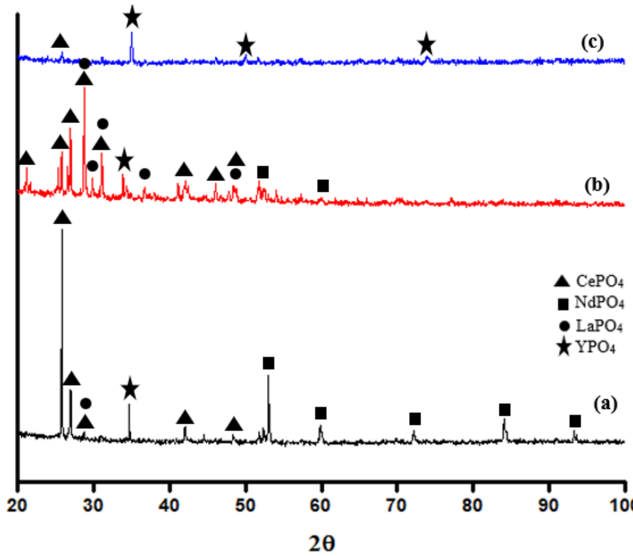

Figure 4. The XRD pattern of (a) natural monazite from Bangka, (b) product from mechanical-magnetic separation, & (c) impurities from mechanical-magnetic separation.

XRD characterization was carried out to determine each phase contained in monazite using data from the Inorganic Crystal Structure Database (ICSD). Based on the results of qualitative analysis (Figure 4), we found two phases in sample MZ #1, namely CePO4 monoclinic (00-032-0199) and NdPO4 monoclinic (00-046-1328). Meanwhile, in samples MZ #2 and MZ #3, we found four phases, namely CePO4 monoclinic (00-032-0199), NdPO4 monoclinic (00-046-1328), LaPO4 monoclinic (01-083-0651), and YPO4 tetragonal (00-009-0377). The results show that the main sample, MZ #2, offers more dominant monazite characteristics and can be explored more deeply. One way is synthesizing single crystals of rare earth metals from monazite samples. Thus, the orientation for product development from monazite minerals is clearer and more realistic.

Particle size

The particle size distribution in samples MZ #2 and MZ#3 was characterized using PSA, which can be seen in Figure 5. The average particle diameter in MZ #2 (918.4 nm) is two times smaller than in MZ #3 (2406.9 nm), with a polydispersity index of 0.694 and 0.899, respectively. This contrasting difference is due to the sieving process after crushing. MZ #2 is a sample that passes filtering, while MZ #3 is a sample that does not. The average diameter in MZ #2 shows that the particle size is still classified as micro because the grinding process is carried out manually using mortar. Thus, to produce nanometer-sized particles, it would be better to use high-energy milling.

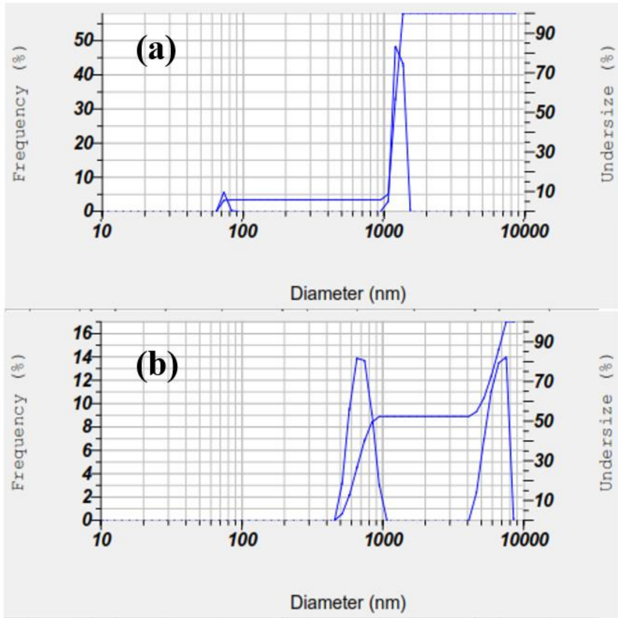

Figure 5. The distribution of particle diameters sieved 325 mesh from mechanical-magnetic separation: (a) product, and (b) impurities. (Note: Qualitatively original measurements; quantitative data was not provided at the time of measurement.)

Potential for monazite-based industrial development

Table 3. Potential for monazite-based industrial development (Dutta et al., 2016)

Element	Potential
Cerium (Ce)	Catalytic converters in cars, colored glass, steel production, refining crude oils.
Lanthanum (La)	Camera lenses, carbon lighting applications such as studio lighting and projector lights, battery electrodes.
Neodymium (Nd)	Powerful magnets used in computed HD, microphones, wind turbines, and hybrid cars, lasers
Yttrium (Y)	Television and computer screens, LED lights, cancer treatment drugs, enhances strength of alloys, catalyst

The potential of these rare earth metal elements can be seen in Table 3. Based on the results of the analysis of monazite samples from tin mine tailings concentrate that has been purified, the dominant elements of the highest rare earth metals are cerium (Ce), lanthanum (La), neodymium (Nd), and yttrium (Y) (Balaram, 2022; Mejame et al., 2021; Milinovic et al., 2021; Peters, 2020). These rare earth metal elements can be further extracted or synthesized and used as supporting or main materials in developing advanced technological industries, especially in Indonesia.

Conclusion

Monazite from tin mine tailings concentrate containing rare earth elements was successfully extracted using mechanical-magnetic separation. These rare earth metal elements need further research to study their potential in various applications.

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Author Contributions
H. A.; conceptualization, methodology, writing – original draft preparation, A. I.; investigation, validation, visualization, P. A. P.; formal analysis, data curation, writing – review and editing. All authors have read and agreed to the published version of manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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