Extraction Efficiency Study of Dysprosium and Neodymium from Acetic Leaching Solution of Xenotime by Di-(2-Ethylhexyl) Phosphoric Acid

(Kajian Kecekapan Pengekstrakan Disprosium dan Neodimium daripada Larutan Lesap Asetik Xenotim oleh Asid Fosforik Di-(2-Etillheksil))

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ABSTRACT

The increasing importance of rare earth elements (REEs) in advanced technologies has prompted extensive research on their extraction, notably neodymium (Nd) and dysprosium (Dy), critical components for neo-magnet production. Researchers are actively exploring Nd and Dy recovery from both primary and secondary REE sources, often employing solvent extraction post-acid leaching for effective separation. In this context, a study focused on extracting Nd and Dy from local xenotime minerals utilizing acetic acid (CH_3COOH) as the leaching solution and Di-(2-ethylhexyl) phosphoric acid (D2EHPA) in kerosene at a 30% concentration as the organic solvent. Energy Dispersive X-Ray Fluorescence (ED-XRF) analysis gauged Nd and Dy concentrations pre and post-extraction. The study identified optimal conditions, showing peak extraction efficiency: 99.4% for Nd and 99.3% for Dy, achieved using a 1M leaching solution concentration and a 1:1 aqueous-to-organic (A/O) phase volume ratio. The extraction process demonstrated highest efficacy at 30 °C within a 20-min timeframe. Consequently, the investigation highlights the potential of acetic acid as a xenotime leaching medium for Nd and Dy extraction with D2EHPA. Therefore, this study proves that CH_3COOH is potentially be used as the leaching media of xenotime for the extraction of Nd and Dy with D2EHPA.

Keywords: Dysprosium; D2EHPA; neodymium; rare earth elements; xenotime

ABSTRAK

Kepentingan yang semakin meningkat terhadap unsur bumi jarang (REEs) dalam teknologi canggih telah merangsang penyelidikan yang meluas terhadap pengambilan mereka, terutamanya neodimium (Nd) dan disprosium (Dy), komponen penting untuk pengeluaran neo-magnet. Penyelidik sedang mengkaji pemulihan Nd dan Dy daripada sumber REE utama dan sekunder, sering kali menggunakan pengekstrakan pelarut selepas pelarutan asid untuk pemisahan yang berkesan. Dalam konteks ini, satu kajian memberi tumpuan kepada pengeluaran Nd dan Dy daripada mineral xenotim tempatan dengan menggunakan asid asetik (CH_3COOH) sebagai larutan pelarutan dan Di-(2-etilheksil) asid fosforik (D2EHPA) dalam kerosin pada kepekatan 30% sebagai pelarut organik. Analisis Serakan Tenaga Pendarfluor Sinar-X (ED-XRF) telah mengukur kepekatan Nd dan Dy sebelum dan selepas pengekstrakan. Kajian ini mengenal pasti keadaan optimum, mendedahkan kecekapan pengekstrakan puncak: 99.4% bagi Nd dan 99.3% bagi Dy, dicapai dengan menggunakan kepekatan larutan pelarutan 1M dan nisbah isi padu fasa akuos-ke-organik (A/O) 1:1. Proses pengekstrakan menunjukkan keberkesanan tertinggi pada suhu 30 °C dalam tempoh 20 minit. Akibatnya, penyelidikan ini menyoroti potensi CH_3COOH sebagai medium pelarutan xenotim untuk pengekstrakan Nd dan Dy dengan D2EHPA. Oleh itu, kajian ini membuktikan bahawa CH_3COOH berpotensi digunakan sebagai medium pelarutan xenotim untuk pengekstrakan Nd dan Dy dengan D2EHPA.

Kata kunci: Disprosium; D2EHPA; neodimium; unsur nadir bumi; xenotim

INTRODUCTION

In today's high-tech world, rare earth elements (REEs) are the unsung heroes behind many innovations. These seventeen elements, which include the lanthanides as well as scandium and yttrium, are crucial for producing powerful magnets, efficient batteries, and advanced optical

devices. Their unique properties enable the development of technologies such as smartphones, electric vehicles, and renewable energy systems. As the demand for cutting-edge technology and sustainable solutions rises, the importance of REEs becomes increasingly evident, highlighting their pivotal role in the technological advancements of the modern era (Zhu & Zhang 2021). More than 60% of the REEs demand are for new applications and will continue to grow due to their extensive use in producing green technologies (Ariffin et al. 2019; Mancheri et al. 2019). Monazite, xenotime, and bastnaesite are the most mined REE-bearing minerals worldwide for the source of REEs (Balaram 2019).

In Malaysia, xenotime has been commercially extracted as a byproduct from alluvial deposits, locally known as amang. It is discovered mainly in the Kinta Valley of the Perak State in Peninsular Malaysia. It was reported that local xenotime contains approximately 61.4% of REE with concentrations of yttrium (Y), ytterbium (Yb), dysprosium (Dy), erbium (Er), and neodymium (Nd) is 45.3%, 5.2%, 4.7%, 2.9%, and 1.6%, respectively (Hazan et al. 2019). The use of Nd and Dy as materials to produce the neodymium-iron-boron (NdFeB) permanent magnets is getting more attention of late due to their high demand as the main component in electronic equipment and green energy technology, such as computers, wind turbines, and electric vehicles (Jowit et al. 2018). Global production of the NdFeB magnets is predicted to increase rapidly as demand for electronic applications and electric vehicles grows (Dushyantha et al. 2020).

Generally, the basic steps in obtaining Nd and Dy from xenotime can be done through digestion, separation, and extraction (Hazan et al. 2019). The digestion process is carried out to break down the mineral orthophosphate lattice and turn it into a by-product known as tri-sodium phosphate (Na_3PO_4). The commonly used method of digestion is either sulfuric acid baking or caustic digestion (Farzaneh, Amir & Ahmad 2017). However, the alternative process of alkaline digestion with NaOH at high temperature or commonly known as alkaline fusion digestion, has been widely used recently for both xenotime and monazite digestion (Hazan et al. 2019; Jacqueline et al. 2019; Norhazirah et al. 2020; Sanjith et al. 2021). This method is reported to be more effective for the mineral decomposition process, where it can eliminate the need for evaporation and acid conversion, which causes an increase in the volume of liquid waste (Abdul Rauf et al. 2022; Mnculwane 2022; Norseyrihan et al. 2016).

The separation process is performed by filtering the solution containing Na_3PO_4 to obtain a precipitate of insoluble REE hydroxide (REOH), followed by leaching in an acidic solution to form an REE-loaded aqueous solution for the solvent extraction process. The acid leaching method is the most studied approach for extracting REE from primary sources, with non-organic acids such as sulphuric (H_2SO_4), hydrochloric (HCl), and nitric (HNO_3)

acids being the most widely utilised leaching agents (Guan et al. 2022; Noorashikin et al. 2013). Many studies have reported on using non-organic acid leaching solution to recover REE. Sun, Kim and Cho (2018) studied the extraction of Nd and Dy from nitrate solution. In his study, Cyanex 272 was used as the extractant diluted in kerosene. Arellano et al. (2020) studied the separation efficiency of Nd from Dy and Tb from chloride solution using PC88A, D2EHPA and Cyanex 272. At the same time, Altansukh et al. (2021) investigated the effect of various organic extractants on the extraction of REE from sulphuric acid leach solution of apatite ore. However, Niskanen et al. (2022) reported that the acid leaching method has recently been shifted to utilize organic acid or specifically acetic acid due to environmental consent. It was stated that using organic acids for leaching rare earth-bearing minerals possibly offers several distinct advantages. These acids are generally less harmful to the environment compared to traditional mineral acids, as they are biodegradable and less toxic, which reduces the risk of long-term environmental contamination (Miller, Zhang & Wang 2019). They also provide greater selectivity in extracting specific rare earth elements, targeting valuable components while minimizing the dissolution of unwanted materials (Wang, Li & Zhang 2020). Additionally, organic acids are less corrosive than strong mineral acids, which helps lower maintenance costs for equipment and reduces the need for specialized materials (Zhao, Liu & Zheng 2021).

Furthermore, using organic acids to leach REE from secondary sources has been extensively outlined of late. Gergoric, Barrier and Retegan (2019) studied the extraction of Nd from neodymium magnet waste leached into various organic acids: glycolic, maleic, and ascorbic. In comparison, Stein, Kasper and Veit (2022) reported on using acetic and citric acids to recover REE in the mobile phone magnet. While REE from calcination product of coal coarse was recovered by using various organic acids with citric acid and DL-malic acid as the best leaching agent was reported by Ji, Li and Zhang (2022). However, using organic acids to leach REE from primary sources is still scarce. Leaching efficiency typically varies between primary and secondary sources due to the difference in material composition. Primary sources are typically more complex and may include a variety of minerals and gangue materials. The REE are often embedded in a matrix that requires breaking down for efficient extraction (Zhou, Li & Li 2018). While secondary sources usually have a higher concentration of REE due to previous processing steps and tend to be more homogeneous compared to primary ores. REEs are often found in simpler, more concentrated forms that making them easier to leach (Wang, Li & Zhang 2022). Therefore, study into organic acids on primary sources can help in developing their application in the effective extraction of REEs from these complex matrices.

In the solvent extraction studies of REEs, several commercial reagents, including D2EHPA, PC88A,

TOPO, Cyanex 272, TBP, Cyanex 923, Cyanex 921, Cyanex 302, and limited bi-functional ionic liquids were employed. Among those solvents, D2EHPA is widely used in the rare earth separation industry because of its high-extraction rate, high selectivity, stable properties, and easy obtainability. In this study, D2EHPA was used to extract Nd and Dy from different molarities of the acetic leaching solution. The study focuses on the extraction efficiency of Nd and Dy with the influence of various acid molarities, aqueous-to-organic volume ratios (A/O), reaction times and temperatures. The concentration of D2EHPA in kerosene was determined for this study.

MATERIALS AND METHODS

REAGENTS AND INSTRUMENT

The xenotime sample used in this study was obtained from Perak. The analytical grade kerosene, NaOH pallet and CH_3COOH acid (M=60.05 g/mol) were supplied by R&M Chemical. The organic solvent D2EHPA was purchased from Sigma Aldrich, Malaysia. Deionized water was used for all experiments in this study. Experiments for extraction of Nd and Dy were conducted with different parameters as listed in Table 1.

The elemental concentration (%) in the acidic leached solution before extraction and in the organic phase after extraction were quantitatively analysed using spectrometric methods with an ED-XRF (EDX-7000, Shimadzu) instrument. The sensitivity tolerance was set at 1% and the measurement error at 0.1%. A Neodymium (Nd) ICP

standard solution with an R 2 value of 0.9976, traceable to Standard Reference Material (SRM) 3135a, was used for comparison in this analytical procedure. Approximately 2 to 3 mL of the sample was poured into a plastic cup. It is essential to select the appropriate support film to provide balanced transmission capabilities, contamination, and strength for the analysis (Irfana et al. 2019). The sample cup was placed on the system under room temperature analysis and was carried out for 5 min on each sample.

XENOTIME DIGESTION BY ALKALINE FUSION

100 g of xenotime was mixed with 200 g of NaOH pallet in a crucible as shown in Figure 1(a). Then, the crucible was put into the furnace to undergo the fusion process for 3 h at a temperature 350 °C. After fusing, the sintered sample (Figure 1(b)) was removed. Distilled water was poured into the crucible, and the sample was left overnight before being transferred to a larger beaker for diluting with 2000 mL of deionized water. The beaker was placed on a heating plate and stirred with a magnetic stirrer for 3 h at a temperature between 60 °C and 70 °C. The sample was then filtered using a vacuum filter. The precipitate collected on the filter paper was washed with deionized water until the wash water reached pH 7 to make certain that the impurities has been removed completely and washing process was effective (Jiang et al. 2023). Water leaching is used to dissolve soluble salts and other by-products that are formed during the thermal decomposition of minerals. It helps to wash away soluble impurities that can interfere with the extraction of REE. The precipitate was dried in an oven

TABLE 1. Experimental parameters for Nd and Dy extraction

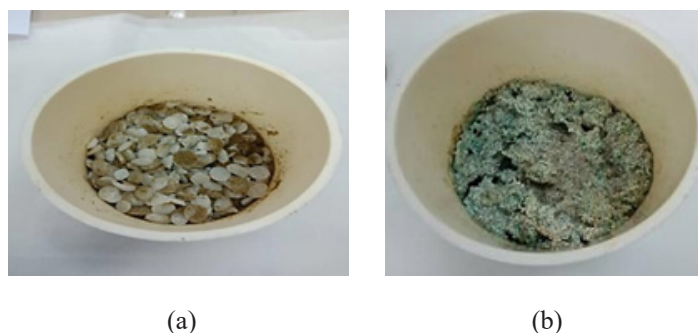| Parameter	Range
Aqueous to organic ratio	1:1, 1:2, 1:3 and 1:4
Extraction temperature, °C	30, 40, 50 and 60
Reaction time, min	10, 15, 20 and 25
Acetic acid molarity, M	0.5, 1, 3 and 5

(a)   (b)

FIGURE 1. (a) Xenotime and NaOH mixture, and (b) sintered sample

at 70 ºC for 24 h to ensure the removal of moisture before preparing the material for further process. By removing soluble components and impurities, the material can be more effectively treated with other reagents or subjected to other extraction methods, such as acid leaching or solvent extraction. Both Nd and Dy are in their elemental forms, which are insoluble in water, including deionized water. Thus, to extract Nd and Dy from their mineral forms, a more aggressive leaching process is required, which typically involves the use of acids to dissolve the mineral for the extraction process.

PREPARING REE-LOADED AQUEOUS SOLUTIONS

The dried precipitate obtained is the REOH. The REE-loaded aqueous solutions were prepared by leaching some amount of REOH into the CH_3COOH with a molarity of 0.5, 1, 3 and 5 M, respectively. The leached solution was stirred for a certain period at a temperature of 70 °C. The concentrations of Nd and Dy in the aqueous solutions before extraction were analysed.

EXTRACTION USING D2EHPA IN KEROSENE

The extractant was prepared by dissolving a specific volume of D2EHPA in kerosene to get a 30% concentration. The aqueous solutions were mixed with D2EHPA at the volume aqueous to organic ratio of 1:1 until 1:4. The mixture of aqueous and organic solutions was stirred using a magnetic stirrer for 15 min at temperatures of 30, 40, 50, and 60 °C, respectively, followed by pouring the mixture into a separatory funnel and leaving for 20 min for the reaction to reach the equilibrium phase before aqueous and organic phases were separated. Figure 2 shows the general steps in the solvent extraction process for the study. The presence of elements in the organic phases was analysed using ED-XRF. The schematic flow diagram for the process of extracting Nd and Dy from acetic acid leached solution is presented in Figure 3.

Extraction efficiency (%E) is calculated to determine the percentage of solute that moves from the aqueous phase to the organic phase. The extraction efficiency is defined in Equation (1), where D is the distribution coefficient, V_A and V_0 are the volumes of aqueous and organic phases accordingly.

$$\%E = \frac{D \times \frac{V_o}{V_A}}{1 + \left(D \times \frac{V_o}{V_A}\right)} \times 100 \qquad (1)$$

The distribution coefficient (D) in Equation (2) is defined as the ratio of the element concentrations in the organic to the aqueous phases at the equilibrium state where C_O and C_A are the element concentrations in percentage (%) in the organic and aqueous phases, respectively.

$$D = \frac{C_O}{C_A} \qquad (2)$$

RESULTS AND DISCUSSION

The concentration of REE before extraction in acid solution at the concentrations of 0.5, 1, 3 and 5M is presented in Table 2. The results showed that the concentrations of Dy and Nd before extraction were 5.19, 6.47, 6.57 and 6.89% and 0.59, 0.90, 1.19 and 1.06%, respectively. Since xenotime is a heavy rare earth element (HREE) phosphate, it is apparent that the Dy concentration is significantly higher than the Nd concentration. Apart from REE, the results also show that the solution contains naturally occurring radioactive materials (NORM), namely Th and U, with a less than 1% composition for both elements.

EFFECT OF CH_3COOH CONCENTRATION

The influence of acid concentration on the extraction behaviour of Dy and Nd by varying it from 0.5M to 5M at O/A =1 and temperature 30 °C was investigated, and the extraction efficiencies of Nd and Dy are shown in Table 3. When the concentration of CH_3COOH rose from 0.5 M to 1 M, the extraction efficiency increased and reached 99.3% (Dy) and 99.4% (Nd). Figure 4 shows the effect of acid concentration on extraction efficiency. When the CH_3COOH concentration continued to increase, the extraction efficiency of Dy and Nd declined slightly to 95.1% and 92.9%. The results show that the extraction of Dy and Nd no longer increases when the concentration exceeds 1 M. The acid is sufficient to consume major elemental oxides and react with rare earth compounds at higher concentrations. The results were valid since Cao et al. (2018) obtained the same outcome and determined that the partially encapsulated Nd and Dy have no opportunity to contact the acid, even though the recovery is no longer limited by the lack of hydrogen ions (H+).

EFFECT OF AQUEOUS-TO-ORGANIC RATIO

The aqueous-to-organic ratio (A/O) volume phase ratios of 1:1, 1:2, 1:3, and 1:4 was used to study their effect on Dy and Nd extraction at constant conditions. Table 4 shows the elemental concentration results from ED-XRF analysis at different A/O volume ratio. The effect of A/O ratio on extraction efficiency is shown in Figure 5. The highest extraction efficiency was obtained at a ratio of 1:1 with 99.3% (Dy) and 99.4% (Nd). However, after the ratio of A/O at 1:2, the extraction efficiency began to decline. While in the A/O ratio of 1:3 and 1:4, extraction efficiency of Dy is 87.6% and 83.3%, and Nd was 86.4% and 79.8%, respectively.

The decrease in extraction efficiency indicates that the solvent has reached its limit or has become saturated to extract the element from the aqueous phase
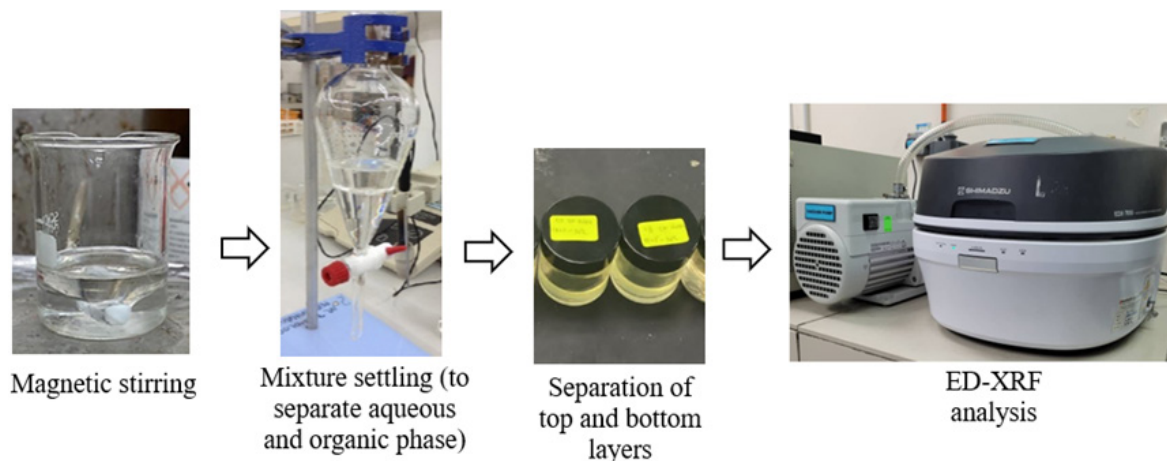
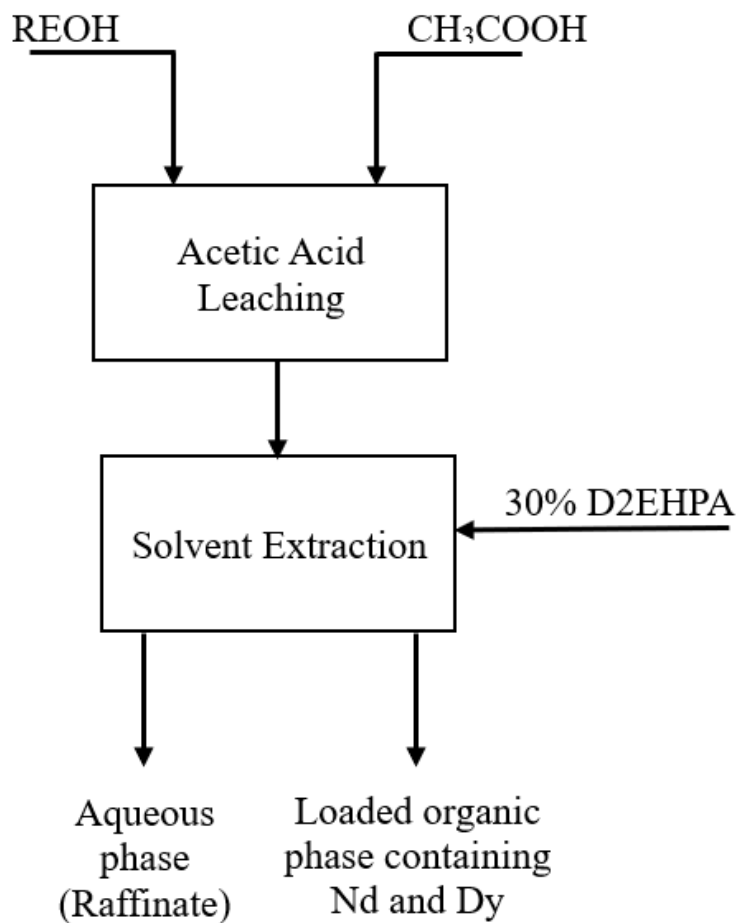FIGURE 2. General step-by-step procedures for solvent extraction process

FIGURE 3. Schematic flow diagram for the Nd and Dy solvent extraction process

TABLE 2. REE concentrations in acetic acid leached solution

REE		Concentration of rare earth elements in acetic acid leached solution (%)			
		0.5M	1M	3M	5M
HREE					
	Y	69.55	71.46	66.86	68.26
	Gd	2.30	2.73	2.35	2.32
	Dy	5.19	6.47	6.57	6.89
	Ho	1.18	1.78	1.48	1.65
	Tm	1.21	1.32	1.38	1.03
	Yb	4.60	4.77	7.33	7.00
LREE					
	Nd	0.59	0.90	1.19	1.06
	Sm	0.68	0.94	0.53	0.40
	La	ND	0.44	0.63	0.66
NORM					
	Th	ND	ND	0.15	0.14
	U	0.55	0.99	0.29	0.22

TABLE 3. Extraction efficiency of Nd and Dy from different CH_3COOH concentrations

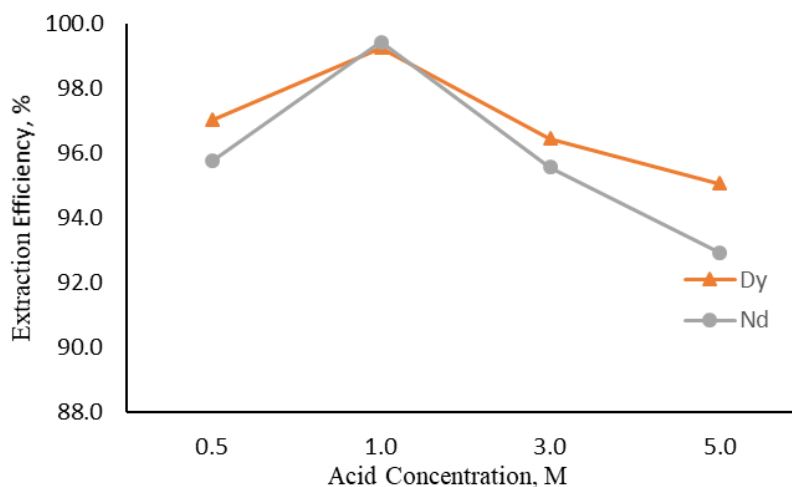| CH_3COOH concentration (M)	Elemental concentration (%)				Extraction efficiency (%)	
	Before extraction in aqueous phase		After extraction in organic phase			
	Nd	Dy	Nd	Dy	Nd	Dy
0.5	0.590	5.192	0.565	5.038	95.8	97.0
1.0	0.900	6.468	0.895	6.421	99.4	99.3
3.0	1.190	6.570	1.137	6.340	95.5	96.5
5.0	1.060	6.886	0.985	6.545	92.9	95.0

FIGURE 4. Effect of acid concentration on extraction efficiency

(Pusporini et al. 2021). Principles of equilibrium between the organic and aqueous phases are frequently used in extraction procedures. Initially, adding more solvent increases the capacity to dissolve and extract the analyte. The equilibrium is established when the system reaches a state where adding more solvent does not significantly change the concentration of the analyte in the organic phase. The organic solvent has a finite capacity to dissolve the analyte. Once this capacity is reached, further addition of solvent will not increase the amount of analyte extracted, resulting in saturation (Hussain & Smith 2023). Therefore, the declining trend in the extraction efficiency in this study may be due to the saturation and solubility limit of D2EHPA.

EFFECT OF EXTRACTION TEMPERATURE

The effect of temperature on extraction efficiency was investigated at 30, 40, 50, and 60 °C, respectively. Table 5 show the results on extraction efficiency of Nd and Dy at different temperature. The effect of extraction temperature on the extraction efficiency is displayed in Figure 6. The extraction efficiency of Dy and Nd decreases from 99.3% and 99.4% to 92.2% and 90.1% as temperature increases from 30 °C to 60 °C, respectively. The extraction activity of REE elements using a temperature of 30 °C is consistent with the results of other studies (Altansukh et al. 2021; Arellano et al. 2020; Pan et al. 2022). Pan et al. (2022) also reported that a high temperature above 35 °C should be avoided because it causes the degradation of the concentration and extraction efficiency of elements and causes the extraction yield to decrease. Nevertheless, Chen et al. (2022) stated that each extraction process has a range of ideal temperatures; for this reason, it is still important to determine the optimal temperature for each specific extraction method and material.

Selecting the suitable extraction temperature is crucial to maintaining the stability of the extracted material since too high a temperature will destroy the structure and activity of the extraction. Therefore, increasing the extraction temperature may potentially decreasing the overall yield or causing the loss of elements as resulted in this study.

EFFECT OF REACTION TIME

As an essential factor impacting extraction yield, the reaction time was also studied to investigate the impact of extraction rate. The results of the extraction efficiency in the range of 10 to 25 min are shown in Figure 7. It was found that the extraction rate was increased from 10 to 20 min when the reaction time was increased. However, the plateau appeared after 20 min in both element curves. The equilibrium state of Nd and Dy reached in 20 min with an extraction efficiency of 99.3% and 99.4%, respectively. Therefore, 20 min was chosen as the most appropriate time of Nd and Dy extraction (Table 6).

COMPARATIVE ANALYSIS BETWEEN ED-XRF AND ICP-MS

The inductively coupled plasma mass spectrometer (ICP-M) has been commonly used as a reliable method for accurately determining REE concentrations at low levels, it has the disadvantage of requiring significant sample preparation, which XRF does not. Moreover, the XRF measurement for six random aqueous samples with different levels of Nd and Dy was compared with the contents analyzed using ICP-MS to determine whether the detection limits of XRF were satisfactory across a range of concentrations. The concentrations of element were measured by an Inductively Coupled Plasma Mass Spectrometer Perkin Elmer ELAN model 9000.

Table 7 displays the comparative elemental concentration (%) of Nd and Dy in sample S1 to S5 by ED-XRF and ICP-MS. The concentration values of ED-XRF (%) was plotted against that of ICP-MS. The linear regression method and the correlation analysis method were both used (Figures 8 & 9).

The analysis has shown that the validation curves for Nd and Dy had slopes that were close to 1. The intercept and linear correlation coefficient (R^2) values of the ED-XRF and ICP-MS were all close to zero and higher than 0.91 in both cases. These findings demonstrate a perfect agreement between the techniques used by the ED-XRF and ICP-MS. The results of the comparison analysis showing that, there are no significant differences between the two techniques.

TABLE 4. Extraction efficiency of Nd and Dy from different A/O ratio

Aqueous-to-organic ratio	Elemental concentration (%)				Extraction efficiency (%)	
	Before extraction in aqueous phase		After extraction in organic phase			
	Nd	Dy	Nd	Dy	Nd	Dy
1:1	0.900	6.468	0.895	6.421	99.4	99.3
1:2	0.900	6.468	0.818	6.090	90.9	94.2
1:3	0.900	6.468	0.778	5.665	86.4	87.6
1:4	0.900	6.468	0.718	5.385	79.8	83.3

The proton-donating effect of the selected ion through the organic phase, which is non-soluble in the aqueous phase, occurs during the mixing of the aqueous (CH$_3$COOH) and organic (D2EHPA) solutions. The ion exchange happens at the hydroxyl group of D2EHPA, which replaces hydrogen with Nd or Dy ion, as shown in Figure 10. The extraction mechanism is combined between solubility and acidic properties of the extractant. Ions are separated from the aqueous phase to the organic phase due to their relative solubility in the organic phase, whereas greater acidity conditions with strong proton dissociation enhance the production of the complex compound between rare earths ion and extractant.
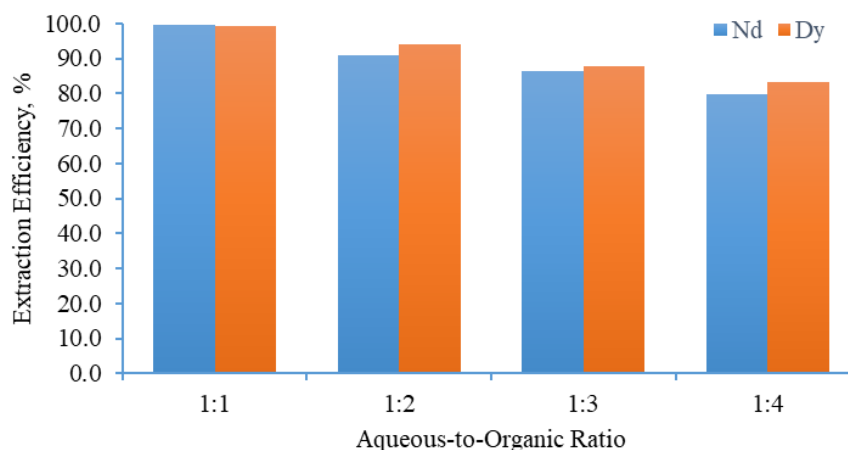

FIGURE 5. Effect of A/O volume ratio on extraction efficiency

TABLE 5. Extraction efficiency of Nd and Dy at different extraction temperature

Extraction temperature °C	Elemental concentration (%)				Extraction efficiency (%)	
	Before extraction in aqueous phase		After extraction in organic phase			
	Nd	Nd	Nd	Dy	Nd	Dy
30	0.900	6.468	0.895	6.421	99.4	99.3
40	0.900	6.468	0.839	6.055	93.2	93.6
50	0.900	6.468	0.813	5.951	90.3	92.0
60	0.900	6.468	0.811	5.965	90.1	92.2

TABLE 6. Extraction efficiency of Nd and Dy at different reaction time

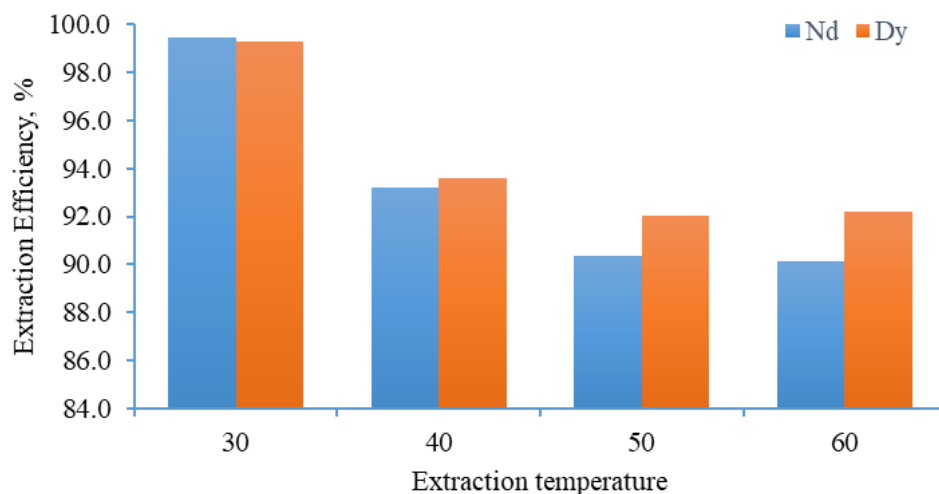| Reaction time (min)	Elemental concentration (%)				Extraction efficiency (%)	
	Before extraction in aqueous phase		After extraction in organic phase			
	Nd	Dy	Nd	Dy	Nd	Dy
10	1.190	5.192	0.871	4.162	73.2	80.2
15	0.900	5.192	0.790	5.038	87.8	97.0
20	0.900	6.468	0.895	6.421	99.4	99.3
25	1.060	6.570	1.055	6.534	99.4	99.3

FIGURE 6. Effect of temperature on extraction efficiency
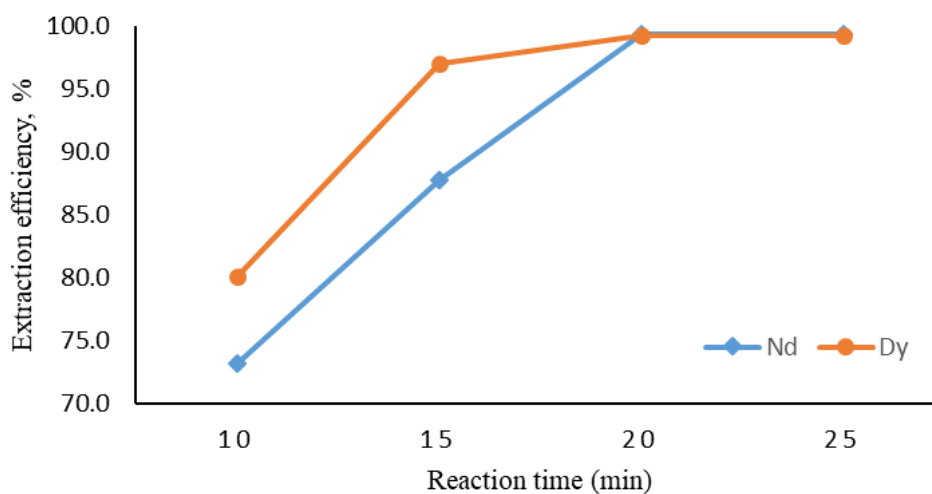

FIGURE 7. Effect of reaction time on extraction efficiency

TABLE 7. Comparative concentration (%) of Nd and Dy in ED-XRF and ICPMS

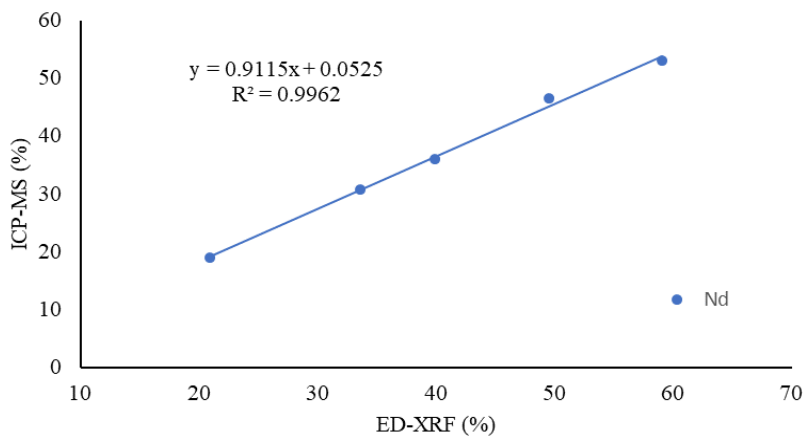| Sample ID	ED-XRF		ICP-MS		Error %	
	Nd	Dy	Nd	Dy	Nd	Dy
S1	39.9	88.8	36.0	81.0	9.8	8.8
S2	20.9	81.4	18.9	74.0	9.4	9.1
S3	59.0	96.6	53.0	90.7	10.2	6.1
S4	33.6	53.4	30.8	45.0	8.4	15.7
S5	49.5	86.4	46.5	82.6	6.1	4.4

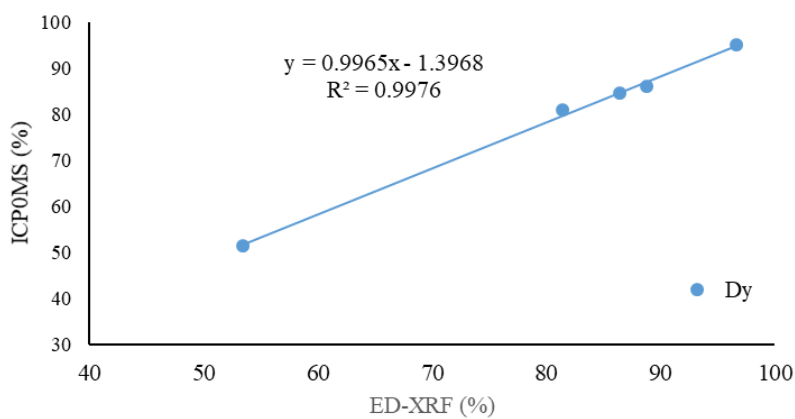FIGURE 8. The graph compares the Nd results from ED-XRF and ICP-MS

FIGURE 9. The graph compares the Dy results from ED-XRF and ICP-MS
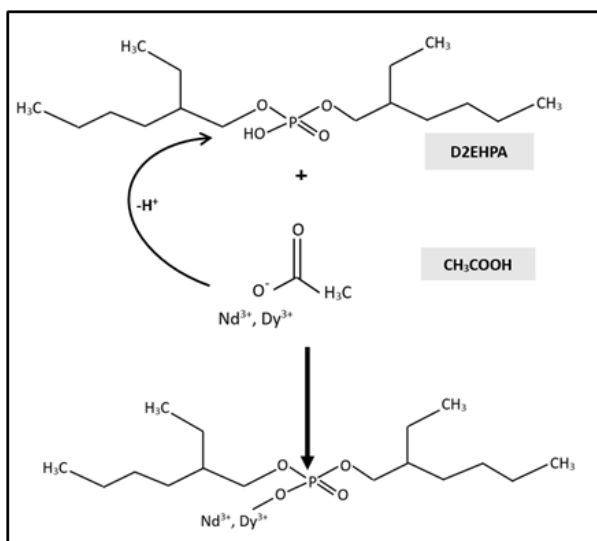

FIGURE 10. Nd and Dy extraction mechanism
using D2EHPA as extractant

CONCLUSION

The present work has shown that Dy and Nd can be successfully extracted from the acetic acid leaching solution of xenotime using 30% D2EHPA through the solvent extraction technique. The leached solution concentration, aqueous-to-organic ratio, extraction temperature and reaction time significantly affect the extraction efficiency of Dy and Nd. It was found that the two elements can be extracted with the highest extraction efficiency of 99.3% (Dy) and 99.4% (Nd) at a concentration of 1M, with an extraction temperature of 30 °C, time of reaction 20 min and the A/O volume ratio equal to 1:1. Overall, this study proves that acetic acid has the potential to be used as a mineral leaching medium for the extraction of rare earth elements.

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