THE DEVELOPMENT OF A PROTOTYPE OF LOW-TENORM ZIRCONIUM OXYNITRATE HYDRATE PRODUCTS FROM LOCAL ZIRCON, WEST KALIMANTAN

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ABSTRACT
Zirconium Oxynitrate Hydrate (ZrO(NO$_3$)$_2$·xH$_2$O) prototype product from Kalimantan zircon sand, or hereafter we mention it as ZON, has been successfully synthesized. The ZrO$_2$ content of 38.62 wt.% in the ZON analysis was higher than that of several commercial products. TENORM (Technologically Enhanced Naturally Occurring Radioactive Material) reduction was obtained from zircon raw materials containing ThO$_2$ and U$_3$O$_8$ of 619.9 and 728.8 ppm, respectively, to become 121.1 and 0 ppm in the ZON. The ZON formation was indicated by the XRD and FTIR characterization.

Keywords: Kalimantan Zircon, Zirconium Oxynitrate Hydrate, Technologically Enhanced Naturally Occurring Radioactive Material, Zircon Sand, Zirconia

INTRODUCTION
In this research, zircon sand is being studied as a by-product of gold mining in Kalimantan, Indonesia. The study shows that zircon sand has the potential to be processed into high-value products. Furthermore, processing industrial waste is essential as a way to support the green chemistry movement. Zircon minerals often contain a Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) that includes U$_3$O$_8$ and ThO$_2$. In Indonesia, the Nuclear Energy Regulatory Agency (BAPETEN) is responsible for regulating the use of TENORM. However, materials with less than 500 ppm uranium and thorium are exempt from federal and state regulations. Zirconium has a high resistance to thermal distortion. Zirconium in the form of ZrC can replace SiC in TRISO kernel fuel for high-temperature reactors. However, using zirconium alloys for nuclear reactor structural materials is challenging due to their low thermal neutron trapping cross-section (~0.185 barns). On the other hand, the presence of hafnium in nature is always associated with zirconium minerals, because the two elements have the same chemical and physical properties. Thus, one of the requirements for nuclear fuel cladding is the hafnium content in zirconium must be less than 100 ppm. The ZON compound is ideal for use in the Zr-Hf separation process. Other researchers have researched synthesizing local ZON solutions for use as feed in the Zr-Hf separation process via liquid-liquid extraction in mixer settlers. In this research, the ZON prototype products are synthesized as solid products using local zircon minerals from the Tumbang Titi area, West Kalimantan Province, Indonesia. The study aims to synthesize, characterize, and compare local ZON prototypes with commercial products.

EXPERIMENTAL
Material and Methods
The local Zircon sand (ZrSiO$_4$) was a byproduct of the gold mining process in Tumbang Titi, West Kalimantan, Indonesia. According to the results of the XRF Epsilon 4 analysis, the weight percentages of...
the oxide elements contained were as follows: 60.57% ZrO₂, 2.11% HfO₂, 28.58% SiO₂, 6.13% TiO₂, 0.45% Fe₂O₃, 1.02% Al₂O₃ and 0.44% total rare earth oxide (REO). It is important to note that the product contains additional ingredients in small quantities. Specifically, it includes 771.9 ppm of SnO₂ and TENORM, which comprises 619.9 ppm of ThO₂ and 728.8 ppm of U₃O₈. Other supporting ingredients were HNO₃, HCl, and mineral-free water.

**General Procedure**

Synthesis and characterization of the ZON prototype product using zircon raw materials from the Tumbang Titi area in West Kalimantan Province, Indonesia are presented in Fig.-1. The synthesis of the ZON is described in the following steps: Zircon concentrate (ZrSiO₄) was mixed with NaOH at the stoichiometric mole ratio of zircon to NaOH in reaction (1). Then, the roasting process was carried out in the furnace at a temperature of 850 °C for one hour. A total of 3000 g of roasted samples were then washed (water leached) using 90 L of water in a leaching reactor at 60 °C, a stirring rate of 100 rpm for one hour, and a triple washing process was performed. Furthermore, the process involved settling, decantation, and vacuum filtration. The outcome of vacuum filtration produced 150 g of solid Na₂ZrSiO₅. This solid was then converted into a ZrOCl₂ solution using 3 L of 4 N HCl, based on the stoichiometric mole ratio in reaction (6), at a temperature of 60 °C for 1.5 hours.

![Fig.-1: Stages of Synthesis and Characterization of the ZON Prototype Product from the Processing of Local Zircon Minerals from the Tumbang Titi Area, West Kalimantan Province of Indonesia](image)

Then, the ZrOCl₂ solution was evaporated, crystallized, centrifuged, filtered, and dried to obtain zirconium oxychloride hydrate - ZrOCl₂·8H₂O (ZOC) as feed in the synthesis of zirconium oxynitrate. Synthesis of zirconium oxynitrate was done by reacting ZOC with HNO₃ according to the mole ratio of ZOC and HNO₃ in reaction (9) using a 1.5 L volume of bench scale stirred reactor with experimental parameters including HNO₃ concentration of 3, 4, 5, and 6N for 40 mins at a stirring speed of 75 rpm and a temperature of 27 °C.

**Detection Method**

The zirconium oxynitrate-ZrO(NO₃)₂ solution resulting from the reaction (9) was then evaporated, crystallized, and dried. The drying results in the form of ZON prototype products were characterized by X-ray fluorescence (XRF) from the Ortec based on a SiLi detector with an Am-241 radioactive source, XRF Epsilon 4 from the Malvern Analytical, X-ray diffraction (XRD) Aeris from Malvern Panalytical, and Fourier Transform Infrared Spectroscopy (FTIR) Alpha II from Bruker. Furthermore, the results of the ZON prototype product characterized by XRF, XRD, and FTIR were compared with the characteristics of commercial ZON products made by Fisher Scientific and ZON synthesized by other researchers.

**RESULTS AND DISCUSSION**

The following are some stoichiometric reactions involved in zirconium processing. They include melting reactions (1-3), water leaching reactions (4-5), acid leaching reactions (6-8), and ZON synthesis (9):¹²⁻¹⁴

\[
\begin{align*}
ZrSiO₄ + 2NaOH &\rightarrow Na₂ZrSiO₅ + H₂O \\
ZrSiO₄ + 4NaOH &\rightarrow Na₂SiO₃ + Na₂ZrO₃ + 2H₂O
\end{align*}
\]
ZrSiO$_4$ + 6NaOH → Na$_4$ZrO$_3$ + Na$_2$SiO$_4$ + 3H$_2$O  
(3)
Na$_2$ZrSiO$_5$ + H$_2$O → Na$_2$ZrSiO$_3$ + H$_2$O + residue of NaOH + impurities dissolved in water  
(4)
Na$_2$ZrSiO$_5$ + 3H$_2$O → H$_2$SiO$_3$ + ZrO(OH)$_2$ + 2NaOH  
(5)
Na$_2$ZrSiO$_5$ + 4HCl → ZrOCl$_2$ + 2NaCl + H$_2$SiO$_3$ + H$_2$O  
(6)
Na$_2$ZrO$_3$ + 4HCl + 6H$_2$O → ZrOCl$_2$·8H$_2$O + 2NaCl  
(7)
Na$_2$SiO$_3$ + 2HCl + H$_2$O → H$_4$SiO$_4$ + 2NaCl  
(8)
ZrOCl$_2$ + 2HNO$_3$ → ZrO(NO$_3$)$_2$ + 2HCl  
(9)

The Characterization of ZON using XRF

The results of the Ortec XRF analysis for the ZON prototype product resulting from the reaction between ZOC and HNO$_3$ are presented in Table-1.

<table>
<thead>
<tr>
<th>Concentration of 1 L HNO$_3$ (N)</th>
<th>ZOC (g)</th>
<th>Zr content in ZON (wt%)</th>
<th>ZrO$_2$ content in ZON (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>17.17</td>
<td>18.21</td>
<td>24.60</td>
</tr>
<tr>
<td>4</td>
<td>22.89</td>
<td>21.46</td>
<td>28.99</td>
</tr>
<tr>
<td>5</td>
<td>28.62</td>
<td>28.36</td>
<td>38.31</td>
</tr>
<tr>
<td>6</td>
<td>34.34</td>
<td>28.59</td>
<td>38.62</td>
</tr>
</tbody>
</table>

According to Table-1, the optimal concentration for synthesizing ZON in a 1.5 L bench-scale stirred reactor is 6 N of HNO$_3$. The reaction was performed by reacting 34.34 g of ZOC with 1000 mL of HNO$_3$ at 27°C and a stirring speed of 75 rpm. The synthesized ZON prototype product showed the highest ZrO$_2$ content of 38.62 wt.%, indicating the best result. To compare the Zr and ZrO$_2$ content in the synthesized ZON prototype product, an analysis was performed using XRF Ortec on Fischer Scientific’s ZON product. In addition, the Zr content in the synthesized ZON prototype product was also compared with commercial ZON products made by Stanford Advanced Materials and CDH, as shown in Table-2.

Table-2: Comparison of Zr and ZrO$_2$ Content in the Synthesized ZON Prototype Product and Fisher Scientific's ZON

<table>
<thead>
<tr>
<th>Type of Product</th>
<th>Zr content in ZON (wt%)</th>
<th>ZrO$_2$ content in ZON (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZON from the synthesis result</td>
<td>28.59</td>
<td>38.62</td>
</tr>
<tr>
<td>ZON from Fisher Scientific</td>
<td>27.33</td>
<td>30.17</td>
</tr>
<tr>
<td>ZON from Stanford Advanced Materials</td>
<td>≥ 19.64</td>
<td>N/A</td>
</tr>
<tr>
<td>ZON from CDH</td>
<td>25.0 – 30.0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Differences in product results may vary due to differences in manufacturing techniques and analytical equipment specifications

Table-2 indicates that the ZrO$_2$ concentration in the synthesized ZON prototype product is higher when compared to Fisher Scientific's ZON, Stanford Advanced Materials' ZON, and CDH's product. Table-3 shows the results of the XRF Epsilon 4 analysis for the content of HfO$_2$ and various impurities like SiO$_2$, TiO$_2$, Fe$_2$O$_3$, ThO$_2$, and U$_3$O$_8$ in the synthesized ZON prototype product.

Table-3: Impurity Contents of the Synthesized ZON Prototype Product

<table>
<thead>
<tr>
<th>Impurity content in ZON (wt.%)</th>
<th>HfO$_2$</th>
<th>SiO$_2$</th>
<th>TiO$_2$</th>
<th>Fe$_2$O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.61</td>
<td>0.77</td>
<td>1.16</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

TENORM: ThO$_2$ = 121.1 ppm, U$_3$O$_8$ 0 ppm (not detected)

Thus, the content of ZrO$_2$+HfO$_2$ in the synthesized ZON product is 41.23 wt%. This result is higher compared to the content of ZrO$_2$+HfO$_2$ in several other commercial ZONs made by Jiangxi Kingan Hi-Tech Co. Ltd., Daichi Kigenso Kagaku Kogyo Co. Ltd., Iwatani, Loba Chemie, and Suvchem Laboratory Chemicals as shown in Table-4.
Table-4: The Comparison of ZrO₂+HfO₂ Contents and Impurities in ZON Prototype Products with Several Commercial ZONs

<table>
<thead>
<tr>
<th>Name of Products</th>
<th>Composition of ZON, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZON of the synthesis result</td>
<td>ZrO₂+HfO₂</td>
</tr>
<tr>
<td></td>
<td>41.23</td>
</tr>
<tr>
<td>ZON-LR of Suvchem Laboratory Chemicals</td>
<td>Min. 35.0</td>
</tr>
<tr>
<td>ZON of Loba Chemie</td>
<td>Min. 35.0</td>
</tr>
<tr>
<td>ZON of Iwatai</td>
<td>≥ 33</td>
</tr>
<tr>
<td>Zirconol ZN of Daiichi Kigenso Kagaku Kogyo Co., Ltd.</td>
<td>25 – 25.6</td>
</tr>
<tr>
<td>ZON of Jiangxi Kingan Hi-Tech Co. Ltd.</td>
<td>20 - 22</td>
</tr>
</tbody>
</table>

*Differences in product results may vary due to differences in manufacturing techniques and analytical equipment specifications.

Table-4 shows that some impurities contents such as SiO₂, TiO₂, and Fe₂O₃ of the synthesized ZON product are still higher compared to the commercial ZON products made by Iwatai, Daiichi Kigenso Kagaku Kogyo Co., Ltd., and Jiangxi Kingan Hi-Tech Co. Ltd. This could occur due to the imperfect filtration and centrifugation processes so that there are still impurities in the form of gel containing SiO₂, TiO₂, and Fe₂O₃ in the zirconyl chloride solution which were not separated.

**The ZON Characterization with XRD**

The synthesized ZON prototype product was characterized by XRD using a radiation wavelength (λ) of 1.5406 Å and 2θ angle between 7° to 50°. The results of the ZON synthesized products with XRD instruments are presented in Fig.-2. In Figure-2, the diffraction pattern of the synthesized ZON show that there are several impurities such as SiO₂, TiO₂ anatase, and ZrO₂. The SiO₂ and TiO₂ impurities are still present in the synthesized ZON because the zircon (ZrSiO₄) raw material has an initial SiO₂ content of 28.58 wt.% and TiO₂ of 6.13 wt.%. However, after going through several process steps such as water leaching, acid leaching, and the reaction between ZOC and 6 N of HNO₃ in the bench scale stirred reactor module for 40 mins, the SiO₂ content decreased from 28.58 wt.% to 0.3 wt.%. Moreover, 0.077 wt.% of SnO₂ and 6.13 wt.% of TiO₂ were reduced to 0.8 wt.% of titanium tin oxide.

![ZON Diffraction Pattern and Impurities Detected by XRD](image-url)

The reduction in SiO₂ is because during the hydrolysis process of Na₂ZrSiO₅, as shown in the reaction (5), H₂SiO₃ is formed, which dissolves in the leachate. There may still be residual SiO₂ that cannot react entirely with NaOH during the zircon smelting process from reaction (1). The remaining SiO₂ contained in the Na₂ZrSiO₅ from reaction (1) will react with HCl in the acid-leaching process to form a SiOCl₂ solution as follows:

\[
\text{SiO}_2 + 2\text{HCl} \rightarrow \text{SiOCl}_2 + \text{H}_2\text{O} \quad (10)
\]

Meanwhile, TiO₂ contained in Na₂ZrSiO₅ reacts with HCl in the acid-leaching process to form a TiOCl₂ solution as follows:

\[
\text{TiO}_2 + 2\text{HCl} \rightarrow \text{TiOCl}_2 + \text{H}_2\text{O} \quad (11)
\]

In the acid leaching process, ThO₂ and U₃O₈ contained in Na₂ZrSiO₅ react with HCl, each possibly forming ThOCl₂ and UOCl₂ solutions from the following reactions:
During the evaporation-crystallization process of the ZrOCl₂ solution, the SiOCl₂, TiOCl₂, ThOCl₂, and UO₂Cl₂ contained in the ZrOCl₂ solution change form of solution to gel due to hot conditions. Furthermore, with the centrifugation process, most of the Si, Ti, Th, and U gels will be separated from the zirconium oxychloride hydrate crystals - ZrOCl₂·8H₂O (ZOC) to become gel waste, as shown in Fig.-1. Because the synthesized ZON product prototype was made from ZOC, there was a reduction in TENORM contained in the synthesized ZON prototype product. The ThO₂ and U₃O₈ contents decreased from 619.9 ppm to 121.1 ppm and 728.8 ppm to 0 ppm, respectively. Figure-2 shows that the other impurity in the prototype of the synthesized ZON product is 2.3% TiO₂ (anatase), which is a metastable mineral from TiO₂ in the form of a black solid and is the first TiO₂ phase formed in many processes due to its lower surface energy. Then, the existence of 0.1% of ZrO₂ is likely to be obtained because there is a possibility that there was a ZrO₂ content in the raw material of Na₂ZrSiO₅ which did not react completely with hydrochloric acid during the acid leaching process. This probably happened in the ZOC synthesis process. Thus, ZOC as a raw material for ZON production may contain ZrO₂ as impurities. The diffraction pattern comparison of the synthesized ZON prototype product, commercial ZON products made by Fisher Scientific, and ZON from other studies is shown in Fig.-3.¹⁵ Figure-3 (a) shows that the diffraction pattern of the synthesized ZON prototype product appears with several peaks, indicating that ZON is in the form of crystals. Then, the three peaks with the highest intensity indicate the formation of zirconium dihydroxy dinitrate (V) 1,33-hydrate crystals. Zirconium dihydroxy dinitrate (V) 1,33-hydrate is another name for zirconium oxynitrate or ZrO(NO₃)₂·xH₂O.¹⁶ The first ZON peak can be seen at 2θ of 9.5377° with an intensity or area of 2439.36, hkl angle of (0 1 0), and a Full Width at Half Maximum (FWHM) value of 0.2816. Then, the second peak at 2θ of 13.0485° with an intensity or area of 1804.33, hkl angle of (1 1 1), and an FWHM value of 0.2789. The third peak has an intensity or area of 806.14 and an FWHM value of 0.2657 at an angle of hkl (0 -2 2) and 2θ of 27.291°. The quality of the crystal can be indicated using the FWHM method, where the smaller the FWHM value and the area, it will show the tendency that the material has higher crystal quality.¹⁷ From the results of the diffraction pattern of the synthesized ZON prototype product, the FWHM value and intensity or area are decreased, so it can be interpreted that the ZON crystals formed have good quality. Figure-3 (a) shows three structured peaks with different intensities. The highest intensity was obtained at 2θ angle of 9.5377° with hkl of (0 1 0). This shows that ZON samples with crystal structure and hkl of (0 1 0) are more perfect than the other orientations.

Fig.-3: Diffractogram of the (a) Synthesized ZON, (b) Fisher Scientific’s ZON, and (c) ZON from other Studies¹⁵

**Characteristics of the ZON by FTIR Analysis**

Characterization of the synthesized ZON prototype product at the use of HNO₃ concentrations of 3, 4, 5, and 6 N was carried out using FTIR with the results of several infrared spectra as shown in Fig.-4. The infrared (IR) spectra of each ZON prototype product formed have a similar pattern marked by spectra in the range of 1030 cm⁻¹ and 1400 – 1380 cm⁻¹. This spectral range indicates the formation of nitrate groups in the ZON synthesized product as stated from the results of ZON synthesis studies conducted by other researchers.¹⁸ The most optimum ZON synthesis results were achieved by using 6 N of HNO₃ and 40 mins reaction time. With the consideration that under these process conditions, the results of XRD analysis on the synthesized ZON prototype product, Fisher Scientific’s ZON, and ZON from other studies had almost

\[ \text{ThO}_2 + 2\text{HCl} \rightarrow \text{ThOCl}_2 + \text{H}_2\text{O} \]  
\[ \text{U}_3\text{O}_8 + 6\text{HCl} \rightarrow 3\text{UOCl}_2 + 3\text{H}_2\text{O} + \text{O}_2 \]
similar diffraction patterns, as shown in Fig.-3. Moreover, the choice of optimum process conditions is also taking into account that the Zr content in the synthesized ZON prototype product is taken to be the highest, as shown in Table-1, and almost the same as the Zr content in commercial ZON products made by Fisher Scientific as shown in Table-2. Another consideration is that the prototype of the ZON product synthesized at the optimum process conditions has a similar spectral shape to the commercial ZON spectra made by Fisher Scientific and the ZON spectra from other studies, as shown in Fig.-5. Figure-5 shows that the results of the FTIR spectra on the commercial ZON samples made by Fisher Scientific have a medium-intensity peak with a wavenumber of 1037.45 cm\(^{-1}\) and a strong peak at a wavenumber of 1403.85 cm\(^{-1}\). Each of those peaks refers to the formation of two different NO\(_3^−\) nitrate anion groups and indicates a coordination bond between the Zr, O, and the NO\(_3^−\) nitrate groups. Then there are two peaks with strong intensities at wavenumber of 1636.45 - 1549.99 cm\(^{-1}\) which indicate OH bonds. There are also peaks with high intensity which are broadening at wavenumber of 3083.52 - 3604.31 cm\(^{-1}\) indicating OH vibration spectra.

Whereas, in the prototype sample of the synthesized ZON product, there is a peak with moderate intensity at 1031.57 cm\(^{-1}\) and a strong peak at 1384.65 cm\(^{-1}\). These two peaks indicate the formation of two different groups of NO\(_3^−\) nitrate anions and denote a coordination bond between Zr atoms with O atoms and NO\(_3^−\) nitrate groups. Then, a peak with strong intensities is found at 1613.74 – 1552.34 cm\(^{-1}\), which indicates OH bonds. Another peak with high intensity is widened at 3049.42 – 3591.96 cm\(^{-1}\), indicating OH vibration. The results of the FTIR spectra on ZON from other studies showed moderate peaks at 1385 cm\(^{-1}\) and 1384.29 cm\(^{-1}\), respectively. These two peaks indicate the formation of the NO\(_3^−\)-nitrate anion group and show a coordination bond between Zr with the O atom and NO\(_3^−\)-nitrate groups. The ZON FTIR spectra results from the two studies show peaks with strong intensities at 1633.64 cm\(^{-1}\) and 1633.27 cm\(^{-1}\) which indicate the OH bonds. We also found high-intensity peaks that broadened each at 3447.43 cm\(^{-1}\) and 3433.17 cm\(^{-1}\), which show the OH vibration. According to the research conducted by other scientists on ZON synthesis, there are two peaks present. The first peak is at 1033 cm\(^{-1}\) with medium intensity, and the second peak is at 1384 cm\(^{-1}\) with high intensity. These peaks indicate the formation of two different groups of NO\(_3^−\)-nitrate anions. Additionally, there is an OH vibration present, which is visible as a broad peak between 3083 - 3700 cm\(^{-1}\). Another peak was discovered at 1630 – 1546 cm\(^{-1}\), indicating strong intensity and OH bonds. The FTIR spectra comparison of the synthesized ZON prototype product to the commercial ZON made by Fisher Scientific and ZON from three other studies indicates that the synthesized ZON prototype product has similar functional groups with the commercial ZON made by Fisher Scientific and ZON from the results of the three other studies.

**CONCLUSION**

The ZrO\(_2\) content in the synthesized ZON prototype product is higher than the ZrO\(_2\) content in Fisher Scientific's ZON. The ZON prototype product contains higher contents of ZrO\(_2\)+HfO\(_2\) or Zr (Hf)O\(_2\) compared to the commercial ZON product from Jiangxi Kingan Hi-Tech Co. Ltd., Daiichi Kigenso Kagaku Kogyo Co. Ltd., Iwatani, Loba Chemie, and Suvchem Laboratory Chemicals. The Zr content in the synthesized ZON prototype product is also higher than the Zr content in the commercial ZON made by Stanford Advance Materials and CDH.
The formation of the ZON prototype product is indicated by: a) characterization of XRD analysis results using Highscore Plus PDF-4 software which shows the formation of zirconium dihydroxy dinitrate (V) 1,33-hydrate crystals, which is another name for zirconium oxynitrate - ZrO(NO$_3$)$_2$·xH$_2$O b) the similarity of the diffraction pattern results and the FTIR spectra between the synthesized ZON product prototype, Fisher Scientific's ZON, and ZON from other studies.

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CONFLICT OF INTERESTS
The authors declare that there is no conflict of interest.

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All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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REFERENCES

[RJC- 8699/2023]