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# Determination of Thorium Distribution Coefficient in Clay Soil From Bangka Belitung for Radioactive Waste Management

**Arya Diva Yana[1], Alizar Ulianas[1], Dadong Iskandar[2]*, Hary Sanjaya[1], Jon Efendi[1]**
[1]Departement of Chemistry, Faculty of Mathematics and Natural Science, Universitas Negeri Padang, Jl. Prof. Dr. Hamka, Padang, Indonesia
[2]Research Center for Nuclear Materials and Radioactive Waste Technology, ORTN, BRIN, KST.BJ. Habibie Serpong, Tanggerang Selatan, Indonesia
*Corresponding Author e-mail: dado001@brin.go.id

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**Abstract**
Radioactive waste is material contaminated by radioactive substances from nuclear activities that pose a danger to the environment and health, so controlled management is required. The purpose of this study was to test the distribution coefficient value of Bangka Belitung clay as an adsorbent to absorb thorium ions. Clay is used because of its large surface area, which helps the adsorption process of metal ions. The results of the study showed that the optimum adsorption conditions were achieved within 10 minutes with an optimum concentration of 100 ppm. Meanwhile, the results of the Langmuir isotherm analysis had a larger $R^2$ value, namely 0.94923. This indicates that the adsorption process is more suitable for the formation of a monolayer. Based on these results, clay can be used in landfill systems to reduce the risk of groundwater pollution.

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## INTRODUCTION

The Radioactive waste is material or equipment exposed to radioactive substances resulting from the operation of nuclear installations (Aini, 2019). Radioactive waste originates from both the energy and non-energy sectors. Energy waste includes waste generated from the nuclear fuel cycle, while non-energy waste includes radioactive waste generated from the use of radiation and radioisotopes in industry, isotope production, and mining. The goal of radioactive waste management is to fulfill national and international legal obligations and ensure the responsible sustainability of nuclear programs (Meilasari et al., 2019, Dewita, 2012).

A landfill is a system designed as the final destination for waste management. Landfills have a base layer that serves as the primary barrier to prevent the migration of leachate, a liquid produced by waste decomposition mixed with rainwater. Therefore, materials with low permeability and the ability to retain pollutants through adsorption and ion exchange are required (Aristo et al., 2019).

Clay, also known as loam, is a material with low permeability and high adsorption capacity. Clay consists of very fine mineral particles, consisting of silica and aluminum, measuring less than 4 micrometers. This material is produced from the weathering of silicate rocks due to geothermal activity and chemical processes (Dani, 2015). Clay can adsorb heavy metal cations and radionuclides well due to its high specific surface area and negative surface charge, making it used in pollution control (Khasanah et al., 2021).

The distribution coefficient (Kd) is used to measure the ability of clay to adsorb radionuclides. This parameter indicates how a substance is distributed between the solid and liquid phases (Kumar et al., 2020). A low Kd value indicates that the substance is more soluble and has the potential to spread in aquatic environments, while a high Kd value indicates that the substance tends to bind to solid particles, resulting in low mobility in groundwater. Therefore, the Kd value is important in determining how effective clay is at blocking pollutants (Latifah & Suseno, 2022).

One radionuclide is thorium. Thorium is an element in the actinide group, usually found in minerals along with uranium and rare earth metals (Iqbal et al., 2017). Physically, this element is silvery white and relatively stable in air, but it is chemically reactive. Naturally, Thorium occurs in certain minerals such as thorite, thorianite, monazite, zircon, xenotime, and allanite (Ngadenin et al., 2023). In monazite, the thorium content is many times greater than uranium. Monazite contains about 12% thorium oxide, but the thorium content in this mineral (Indryati et al., 2023). Thorium is a raw material used in the manufacture of nuclear fuel in the future as a substitute for uranium, making it a highly strategically valuable material (Ngadenin et al., 2014). Much tetravalent thorium is found in nature, such as in areas used for tin mining on Bangka Belitung Island (Dewita & Rahmawati, 2015). The results are expected to contribute to the development of more efficient and sustainable standard methods for wastewater treatment applications.

This study aims to identify ways to mitigate the impact of radiation from the tin industry and related materials on the community and the environment in Bangka Belitung. This study will develop applicable technologies to mitigate the effects of radiation on workers and the environment through tin sand extraction, washing, separation, and disposal. Additionally, this study will provide an evaluation of radiation safety regarding the disposal of TENORM waste in Bangka Belitung following closure, as well as identify suitable sites for TENORM waste disposal (Sucipta, 2009).

The final disposal of TENORM will reduce radiation hazards to the public and the environment (Pontedeiro et al., 2007). To carry out the final disposal of TENORM waste, the following steps must be taken: first, criteria for the disposal site and landfill design are established and formulated based on IAEA standards and expert opinions; second, data and information regarding site characteristics, technology, storage safety, and landfills are researched and collected from various sources; and third, this data and information are evaluated and used as the basis for the study (Sucipta et al., 2020). Final disposal determines the type of soil selected based on factors such as soil permeability, the distance between the groundwater table and the ground surface, and seismicity. Additionally, the selected site must consider the Spatial and Regional Planning (RTRW), land ownership, land area, and other factors (Setiawan et al., 2025). An example of a TENORM waste final disposal design is shown in Figure 1 below.

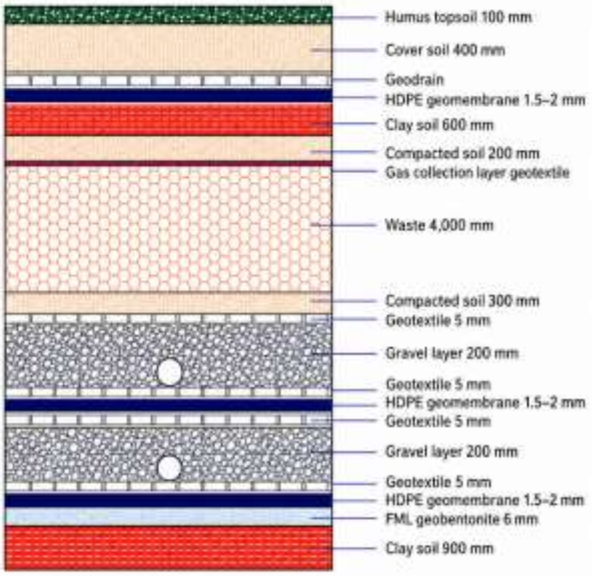


**Figure 1. Design of a final disposal site for TENORM waste**

# METHOD

## Syntesis and Characterization

The synthesis process was carried out by grinding the clay using a mortar and pestle, then sieved with a size between 50 mesh and 65 mesh. Next, 1 gram of the refined clay was weighed, then placed in a 50 mL centrifuge tube and labeled. Then, a 100 ppm thorium solution was made in a 500 mL volumetric flask, then 30 mL was taken and placed into a centrifuge tube containing 1 gram of clay. The centrifuge tube containing the sample was shaken at a speed of 60 rpm for various contact times, namely 5, 10, 15, 20, 30 and 60 minutes. After contact, the solution and clay granules were separated using a centrifuge for 5 minutes at a speed of 3000 rpm. Then the separated solution was obtained and tested using a UV-Vis spectrophotometer. The same procedure was also carried out for concentration variations, namely 100, 150, 200 and 250 ppm with optimum contact time.

Figure 2. Clay Synthesis and Characterization Work Scheme

## RESULTS AND DISCUSSION

The UV-Vis Spectrophotometer test on contact time variations was carried out to directly measure the concentration of residual thorium in the solution after contact with clay. The results of the concentration measurements from the UV-Vis spectrophotometer were then used to calculate the distribution coefficient (Kd) value and displayed in the form of a graph of the relationship between contact time and distribution coefficient, so that the effect of the length of contact time on the adsorption process can be known. The formula for calculating the distribution coefficient (Kd) value is:

$$Kd = \frac{(C_0 - C_1) \times V}{m.C_1}$$

While, Kd: Distribution Coefficient, $C_0$: Initial Concentration (ppm), $C_1$: Final Concentration (ppm), V: Thorium Volume (mL), m: Sample Mass (g) (Harto et al., 2014).

### Contact Time Variation

Figure 3 shows the relationship between contact time variation and the distribution coefficient value. The optimum value is shown at the 10th minute (Kd = 131.2591 mg/L), indicating that the adsorption process is rapid in the initial stage due to its ability to interact and bind dissolved molecules or ions on the clay surface.

Table 1. Contact Time Variaion Test Results

| Time (minutes) | Initial Concentration ($C_0$) ppm | Final Concentration ($C_1$) ppm | Distibution Coefficient (mL/g)/ 5 | Adsorption (%) |
|---|---|---|---|---|
| 5 | 100 | 26,7758 | 82,0415 | 73,2242 |
| 10 | 100 | 18,6036 | 131,2591 | 81,3964 |
| 15 | 100 | 21,4424 | 109,9097 | 78,5576 |
| 20 | 100 | 21,0106 | 112,7851 | 78,9894 |
| 30 | 100 | 24,4404 | 92,7476 | 75,5596 |
| 60 | 100 | 25,7468 | 86,5193 | 74,2532 |

Table 1 and Figure 3 show that the distributic coefficient (Kd) value increased rapidly in the fir five minutes and reached a peak at the 1( minute. This indicates that the adsorption proce took place rapidly in the initial stage because K has the ability to interact and bind dissolve molecules or ions on the clay surface. Aft reaching the peak, Kd decreased from the 15th the 60th minute. This occurs because a desorptic process has taken place, namely the release adsorbed substances from the surface of tl adsorbent into the solution.

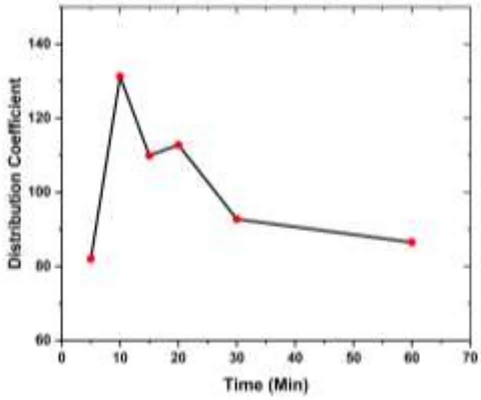


Figure 3. Contact Time Variation Graph

Kinetically, this pattern is similar to the Pseudo-first-order model. The pseudo-first-order model is based on the notion that a change in solute take-up rate can be directly related to the differrence in saturation concentrations and the amount of solid take-up over time. This model is particularly applicable during the first phase of adsorption processes (Irfan et al., 2022). In this model, the adsorption rate is high in the early minutes, then slows down as the adsorbent surface approaches saturation, while the difference in Kd more indicates changes in the concentration ratio caused by initial ($C_0$) and final ($C_1$) variations at each measurement point (Syarifah et al., 2016).

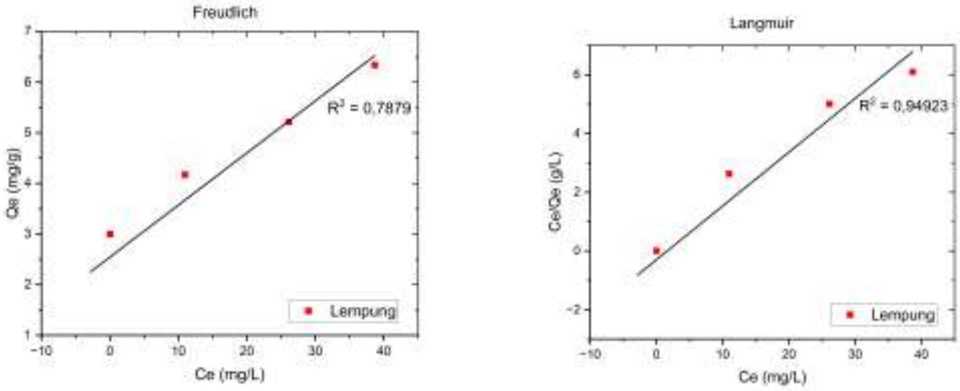
## Concentration Variation

Table 2 above shows data obtained from variations in concentration tested using a UV-Vis spectrophotometer to determine the relationship between the concentration of thorium in the solution and the amount of thorium adsorbed on the clay.

Table 2 shows that at a concentration of 100 ppm, the complex formation process with thorin is complete and provides the best response for measurement (Soetopo et al., 2012). The number of $Th^{4+}$ ions is sufficient to bind all available thorin molecules at this point, so that the resulting complex color reaches its highest intensity and is stable. If the thorium concentration is above 100 ppm, increasing the number of thorium ions no longer increases the color intensity (Junara et al., 2016). Figure 4 shows that the Freundlich isotherm model indicates a low adsorption process, because the coefficient of determination ($R^2$) value of 0.7879 is generated from the relationship between the equilibrium concentration (Ce) and the adsorption capacity (Qe).

Table 2. Concentration Variaion Test Results

| Initial Concentration ($C_0$) ppm | Final Concentration ($C_1$) ppm | Distibution Coefficient (mL/g) / 5 | $C_1$ (mg/kg) | Ce (mg/L) | Qe (mg/g) | Ce/Qe (g/L) |
|---|---|---|---|---|---|---|
| 100 | 0,013 | 230739,2 | 13 | 0,013 | 3,000 | 0,0043 |
| 150 | 10,9672 | 243,5 | 10967,2 | 10,9672 | 4,171 | 2,6294 |
| 200 | 26,1182 | 84,9 | 26118,2 | 26,1182 | 5,216 | 1,6518 |
| 250 | 38,6668 | 47,6 | 38666,8 | 38,6668 | 6,340 | 1,8469 |



(a) (b)

Figure 4. (a) Freundlich Isotherm Graph and (b) Langmuir Isotherm Graph

Figure 4 shows that the Freundlich isotherm model indicates a low adsorption process, because the coefficient of determination ($R^2$) value of 0.7879 is generated from the relationship between the equilibrium concentration (Ce) and the adsorption capacity (Qe). According to the Freundlich adsorption isotherm model, the adsorption mechanism occurs on the surface of the adsorbent.

The adsorbate forms multiple layers on the adsorbent surface, and each layer has a different adsorption capacity depending on its distance from the adsorbent surface. The farther the surface layer is from the adsorbent surface, the lower the adsorption capacity (Dalimunthe et al., 2023).

However, the Langmuir isotherm model has a distribution coefficient value of 0.94923 which indicates that adsorption occurs on a homogeneous surface with uniform energy without interaction between adsorbate molecules that form a monolayer (Aziz et al., 2017).

This model assumes that multilayer stacking does not occur because each active site on the adsorbent surface, such as the hydroxyl group (–OH) on kaolinite, can bind only one ion. This applies to systems where highly charged ions such as thorium ($Th^{4+}$) are adsorbed, which tend to form specific bonds through surface complexation mechanisms. When experimental data show a high fit to the Langmuir model (for example, a coefficient of determination $R^2$ value approaching 1), it can be concluded that specific interactions between the adsorbate and active sites govern adsorption rather than intermolecular interactions in solution. According to the Langmuir model, adsorbate absorption occurs only on homogeneous surfaces where the energy of each adsorption site is the same. Furthermore, on the adsorbent surface, there is only a single layer of saturated adsorbates that do not interact with each other (Salah et al., 2019).

## CONCLUSION

Based on the results of the research that has been conducted, that the clay of the Bangka Belitung Islands adsorbs thorium effectively. The optimum contact time is 10 minutes with a distribution coefficient (Kd) value of 131.2591 mg/L, and an optimum concentration at 100 ppm and the adsorption character follows the Langmuir isotherm model with a coefficient of determination ($R^2$) value of 0.94923, which indicates the formation of a monolayer up to maximum capacity.

## RECOMMENDATION

Future studies should further investigate acidic to basic pH conditions, test the surface area of the adsorption material to improve the method's efficiency. Furthermore, further evaluation using real water samples from the Bangka Belitung region should be conducted to assess the applicability of this method.

This study used a simple system (one ion), which is not representative of complex radioactive waste conditions. The adsorption capacity and surface area of natural clays are relatively low, and material characterization and long-term stability testing, including desorption, are very limited. Furthermore, few studies have conducted this research. Therefore, our understanding of the distribution and stability of thorium between the solid and solution phases under various environmental conditions is still incomplete.To assess the effectiveness and safety of the adsorbent, a test was conducted using the distribution coefficient (Kd) to measure the clay's ability to distribute and retain thorium between the solid and liquid phases.

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