Simulation Study of Thorium Separation from Monazite Mineral

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Abstract: Growth of electricity demand is rapidly increasing. Several method to supply electricity such as utilizing renewable energy has been used. Nuclear energy is still the best choice to produce electricity. Instead of using uranium as a fuel, utilization of thorium as a nuclear power plant fuel has been investigated since 1950. Thorium is much safer than uranium since it does not produce hazardous by product which can be used as an explosive material. Thorium can be found widely in Indonesia together with uranium and many other rare earth material such as lanthanides group. Separation is needed before thorium can be used as a fuel. In this article, preliminary study of thorium separation from monazite mineral has been conducted. The end product of this study is a plant design for thorium separation process. This study used secondary data which has been lab scale experimental. The data was then predicted by using mathematical model, calculated data were then compared to the experimental data. The model used in this study was in accordance with the experimental data, where R^2 for thorium, uranium and rare earth element are 0.9591, 0.7591 and 0.9889 respectively. The developed model in this study then can be used for thorium separation process modelling using METSIM.

1 INTRODUCTION

In 2018, the growth of electricity demand in the world is increasing twice as the global demand of energy which is 900 TWh. From overall electricity generation, gas and coal are still have the biggest contribution. While, the generated electricity from renewable energy resources only able to supply less than 10%. More than 90 TWh of electricity generation contributed by nuclear energy (IEA, 2019). As a promising alternative energy in the world, there are 450 nuclear reactors in total which is operated in over 30 countries around the world. There are six type of different reactor which are used in the nuclear power plant namely Boiling Light-Water Cooled and Moderated Reactor (BWR), Fast Breeder Reactor (FBR), Gas Cooled, Graphite Moderated Reactor (GCR), Light-Water Cooled, Graphite Moderated Reactor (LWGR), Pressurized Heavy-Water Moderated and Cooled Reactor (PHWR) and Pressurized Light-Water Moderated and Cooled Reactor (PWR). PWR reactor type is the most popular in the world which is being used by more than 60% of nuclear power plant around the world (PRIS, 2019).

The electricity of nuclear plant was obtained from spin large turbines which is operated by the steam from water heating process. The water heating process is utilizing a heat produced during nuclear fission process to convert the water into a steam. uranium oxide (UO_2) is commonly used as a fuel of nucler reactor, meanwhile not all of the uranium product can be used as fuel. There are only 0.7% of of natural uranium can undergo a fission process and produce high energy. Naturally, mined uranium consist of 0.7% uranium-235 (U-235) and 99.2% of uranium-238 (U-238) (WNA, 2018). In the other hand, uranium have some disadvantages which are having deleterious health effect and also create a radioactivity waste issue. The leaked radiation from nuclear power plant can last for centuries and create a problem for the next generations. U-238 also very dangerous since during the fission process it can transmute into neptunium and then into plutonium-239 which is a byproduct that can be used as a weapon.

Thorium has become an alternative nuclear power plant fuel to replace U-235. In nature, thorium is more abundant rather than uranium, Its oxide form, ThO_2 also relatively inert compared to

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UO_2 which is easily oxidised into a more dangerous byproduct (Dewita, 2012). Thorium can be found easily in a mineral monazite which is the second most important rare earth (RE) mineral source containing thorium and uranium in associated metals (Amaral and Morais, 2010). Studies on the thorium fuel cycle had been started from 1950 and still continuing until recent centuries (Oettingen and Skolik, 2016).

There are numerous research have been conducted to separate thorium from mineral monazite/monazite sands. Hughes and Singh (1980), introduced solvent extraction process of monazite sulphate solution by using secondary amine Adogen 283. A maximum thoria concentration of 18 g/l was obtained by using ammonium carbonate solution as a stripping agent in the 9-10 pH range. Ali et al. (2007) develop a process to obtain the thorium from the hydrous oxide cake from which uranium has been removed. It was found that Aliquat-336 can be prefentially extract thorium from HNO_3 solutions. The extraction efficiency was found to be 80% and the stripping process efficiency was 82%. Amaral and Morais (2010) investigation, stated that four stages of extraction step, five stages of stripping process and one stage of solvent generation able to separate 99.9% of thorium and 99.4% of uranium from aqueous solution with only less than 0.001 g/L metal contents in the extract phase.

Further process of thorium separation from uranium has been investigated by Trinopiawan and Sumiarti (2012). Two different solvent were used to precipitate the thorium from uranium, it gave a satisfying results where sulfuric acid able to obtain 96.99% while chloride able to obtain 98.05%. Simulation study in the research of rare earth elements especially in nuclear power plant is very impoertant. It might help the researcher on predicting the separation process of thorium to obtain an advance and optimum process. Larochelle and Kasaini (2016) were presenting an alternative model for designing and optimizing rare earth element solvent extraction process using METSIM. The simulation results has been compared to pilot plant and it shows a good accordance with the real solvent extrction process. Advantages of process simulation in rare earth process are able to minimize the complexity of the design by only using a simple batch extraction data and also able to optimize the process theoretically based on existing variables and parameters.

This research will discuss on the preliminary of simulation study of thorium separation process plant. In the future, this study might have a worth contribution for the thorium separation process plant.

2 RESEARCH METHODOLOGY

2.1 Thorium Separation Process Flow Diagram

The flow diagram process for thorium separation process is shown in Figure 1.

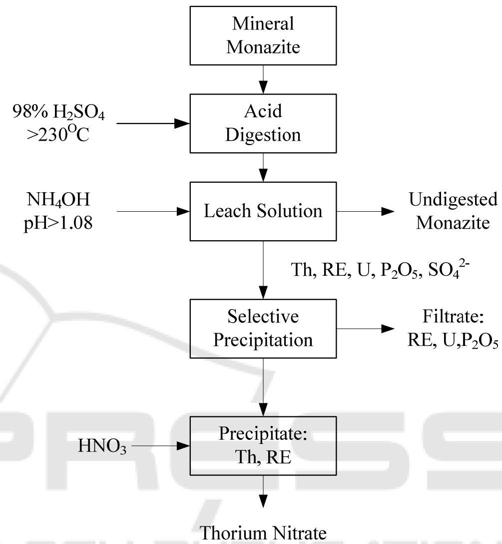

Figure 1: Flow diagram process for monazite digestion and thorium recovery (Al-Areqi, 2016).

2.2 Data Observation

The secondary data was obtained from the previous work related to thorium separation process. Data set of monazite digestion process was obtained from Anggraeni et al. (2015). While data for thorium separation from uranium by using precipitation process were obtained from Trinopiawan & Sumiarti (2012).

2.3 Simulation Study

This simulation study was conducted by using METSIM software with licensed owned by Universiti Malaysia Pahang.

3 RESULTS AND DISCUSSION

Based on Figure 1, the flow sheet of thorium separation process was created in METSIM Software. The detail of the flow sheet is shown in Figure 2.

Table 1: Kinetic constant for thorium concentration data regression analysis.

Vari able	Value	95% confidence interval	R^2
k	0.6933	± 0.0039124	0.9591
n	1.1009	± 0.0357526	

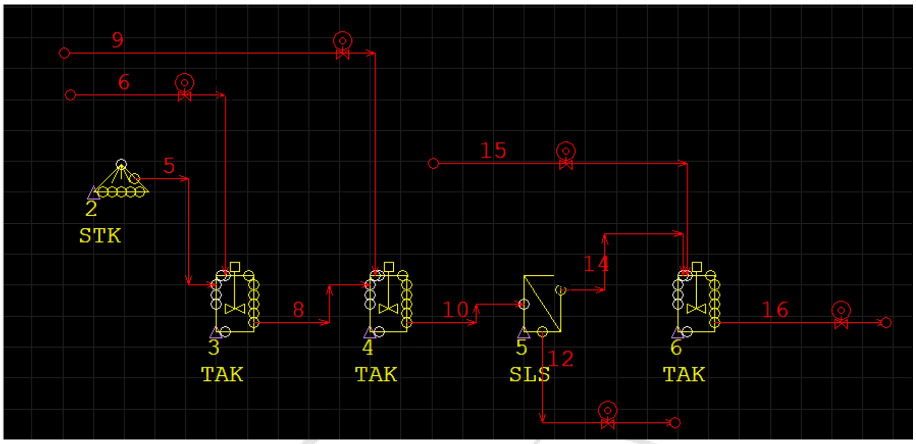

Figure 1: Flowsheet of Thorium Separation Process.

Each of the simulated equipment, required a specific input equation to represent the current process. Acid digestion process of a monazite, requires a kinetic parameter to simulate the rare earth material separation from monazite mineral. The data was obtained from Trinopiawan and Sumiarti (2012). The predicted model of ihorium in acid digestion are shown in Figures 2 and Table 1. While the kinetic model used is shown in Equation 1.

$$C_{Th} = \left[C_{Th,0}^{(1-n)} - (1-n)kt\right]^{1/(1-n)} \qquad (1)$$

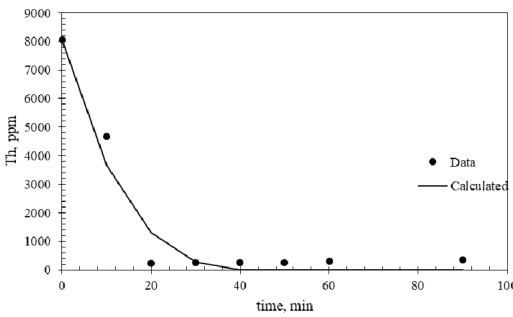

Figure 2: Simulation result of thorium concentration over digestion time.

Based on the R^2 value, the simulated result of Thorium concentration was in accordance with the data experiment.

In the digestion process of monazite, besides thorium there is also uranium which already commonly used in nuclear power plant as a fuel. The model for uranium separation during digestion process also predicted using Equation 1 and the results are shown in Figure 3 and Table 2.

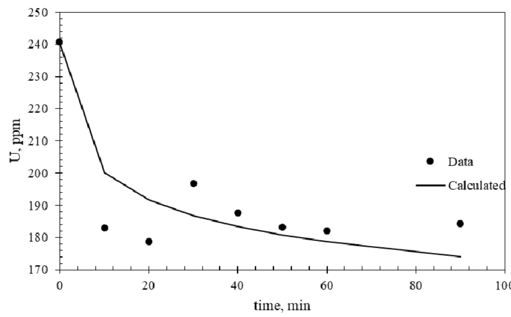

Figure 3: Simulation result of uranium concentration over digestion time.

Table 2: Kinetic constant for uranium concentration data regression analysis.

Vari able	Value	95% confidence interval	R^2
k	16.38806	± 3.583056	0.7591
n	2.38E-38	± 4.48E-37	

A scattering data experiment used in this simulation caused a slight value of deviation and affect the R^2 value.

The other components inside monazite mineral were analyzed as a total Rare Earth Element (REE) concentration. This component can not be eliminated during the simulation due to its existence is very large in monazite mineral. The predicted model of REE concentration are shown in Figure 4 and Table 3.

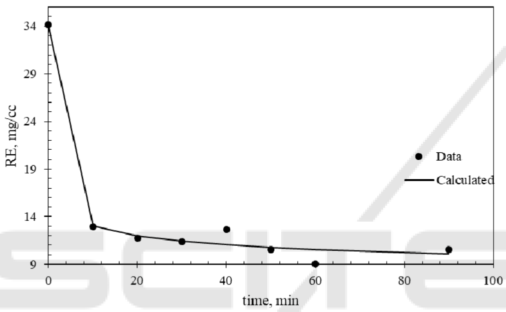

Figure 4: Simulation result of rare earth (RE) concentration over digestion time.

Table 3: Kinetic constant for rare earth (RE) concentration data regression analysis.

Vari able	Value	95% confidence interval	R^2
k	9.57258	± 7.307524	0.9889
n	3.33E-12	± 6.21E-11	

From Figure 4 and Table 3, it can be seen that the equation able to represents the rare earth material digestion process over acid condition. The R^2 value is close to 1 indicated that the model is fit enough with the experimental data.

In the future, this model is going to be used in the METSIM simulation to predict the thorium separation process from monazite mineral.

4 CONCLUSION

In this study, the flow sheet of thorium separation from monazite mineral has been prepared. All the model have been developed by using secondary data. The result shows that model for thorium and RE digestion process is in accordance with the experimental data, while model for uranium digestion process is quite far from the data but it still manageable to be used in the upcoming simulation.

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