Undergraduate Thesis Prospectus

Design of a Thorium Extraction Process from Monazite Sand

(technical research project in Chemical Engineering)

Nuclear Expansion: The Debate Surrounding America's Energy Future

(sociotechnical research project)

by

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technical project collaborators:

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Anna Winter

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.
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Technical advisor: Eric Anderson, Department of Chemical Engineering

STS advisor: Peter Norton, Department of Engineering and Society

General Research Problem

How can the United States generate sufficient, safe, and sustainable energy for the future?

Hydrocarbon fuels such as coal and oil currently provide 62.7% of the electricity generated in the United States, but their consumption has had significant environmental consequences (EIA, n.d.). Carbon dioxide and methane from the combustion of hydrocarbon fuels contribute to climate change, which if unchecked may drive 1 million wildlife species into extinction (IPBES, 2019) and submerge coastal cities such as Miami and Boston under rising seas (Hallegate et al., 2013). To avoid these devastating outcomes, environmentally friendly energy sources must be adopted.

The capacity of U.S. wind and solar installations has been growing, but their output is highly variable and they may never be able to generate sufficient electric power to supply all demand. Energy-dense, environmentally friendly energy sources are needed.

Pursuit of a Worthy Alternative: Extraction of Thorium from Monazite Sands

How can a thorium extraction process from monazite sand be designed to satisfy the needs of Virginia's nuclear reactors?

General Information

This project will be completed under the supervision of my capstone advisor, Eric Anderson, of chemical engineering. This is a team project; my teammates are Ben Newhouse, Samuel Ong, Peter Sepulveda, and Anna Winter.

Project Objectives and Limitations

Currently, uranium compounds are the major feedstock for nuclear power plants, but thorium presents a potentially safer, more abundant, and more efficient alternative []. Monazite sands rich in thorium phosphates are the ideal sources for this element, and while literature details thorium extraction processes at the laboratory scale, no public work describes this process at the scale necessary to provide for a state the size of Virginia. This project aims to design a process to purify monazite sand into thorium oxide while creating a byproduct stream containing rare earth metal and uranium compounds and scale this process to satisfy the needs of Virginia's nuclear reactors.

Figure 1 describes a process flow diagram (PFD) which outlines the target process. The elements enter the process as phosphate compounds in monazite sand and are first leached with sulfuric acid. Following this acid digestion, the rare earth elements and uranium are separated in a pH-controlled precipitation vessel using ammonium hydroxide. The thorium hydroxide obtained from precipitation is mixed with nitric acid to form thorium nitrate that then undergoes extraction with tributyl phosphate in kerosene. The last step of the purification converts thorium nitrate into thorium oxalate using oxalic acid to be calcined into thorium oxide. The thorium oxide exiting the process is 98% pure, and is suitable for use in a thorium reactor.

This project aims to understand the chemistry within this process and design major process equipment at the desired scale. This project will produce a design of this process consisting of all material and energy balances, specifications for major pieces of equipment, safety and environmental considerations, and an economic analysis. Further purification of uranium and rare earth metals into their saleable products are outside the scope of this project, but future work could include the purification of these compounds.

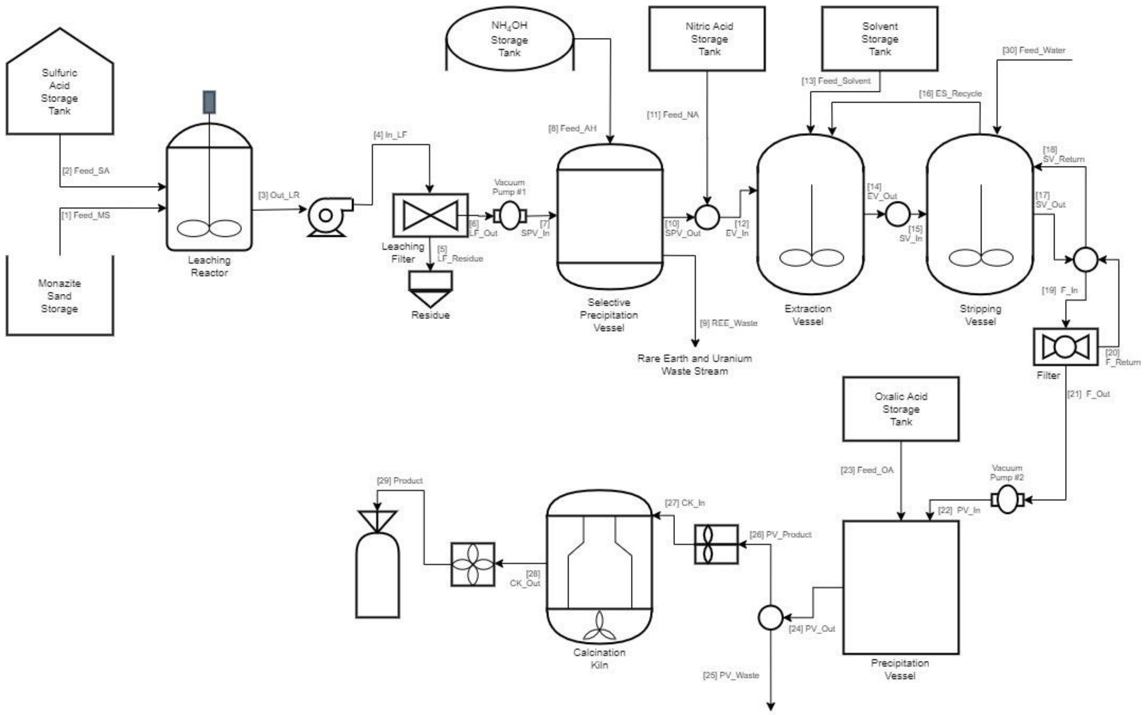

Figure 1: Basis for monazite digestion process flow diagram adapted from Salehuddin et al. (2019). Diagram produced by Anna Winter.

Project Organization and Methodology

This project will be completed over the course of two semesters as a part of CHE 4438/4476. Group meetings will be held twice a week on Mondays and Thursdays at 5-6 pm to assign work for the upcoming weeks and check work from previous weeks. Individual work assignments will be checked by all group members and difficulties completing assignments will be communicated to the rest of the group via text messages. During team meetings, team members will ensure that other members understand what is being accomplished individually, and that the science and processes being used are clear. All design files will be shared over Google Drive to ensure consistent and easy access.

Aspen Plus will be used to simulate the overall process, and an additional plugin created by OLI Systems will be used for the ionic properties of Th, U, and other heavy metals found in monazite sand. Data for the design process will be obtained from a process designed by Iowa State University written in 1957, published in 2005. Modern economic data will be obtained from Salehuddin et al.

Nuclear Expansion: The Debate Surrounding America's Energy Future

Since 2011, how have U.S. environmentalist groups competed to characterize nuclear energy's merits as a source of electric power?

Nuclear power plants have the potential to provide about 8 TWh of power per year in the U.S. with zero carbon emissions (WNA, 2020). The Energy Policy Act of 2005 promoted the expansion of U.S. nuclear power capacity, but by 2011 the expansion had ebbed. In the U.S., 98 nuclear power plants generate 20 percent of total electric power, but this share has declined (WNA, 2020). Environmentalists are split on the merits of nuclear power, and the discussion surrounding its use will shape the U.S.'s energy future.

Researchers have investigated nuclear power as a sociotechnical problem. Jasanoff and Kim (2013) compared attitudes toward nuclear power in the U.S. and South Korea. They found that Americans generally believe nuclear power's dangers outweigh its potential benefits, while Koreans were willing to accept the associated risks. Sovacool (2009) contends that incomplete economic information about renewable energy deterred its implementation, while both utilities and consumers are comparatively accepting of nuclear power. In a study of opponents of nuclear power in the U.S., Taylor (2013) finds two varieties of opposition: some critics condemn nuclear power for its environmental hazards; others find it inconsistent with democratic institutions.

Participants include groups such as the Sierra club, which condemns nuclear power because of the environmental hazards of nuclear waste (Sierra Club, 2020). The Nuclear Information and Resource Service (NIRS) opposes nuclear power on the grounds that it is expensive and tends to “contribute to further proliferation of nuclear weapons materials.” NIRS contends that commitment to nuclear power would “squander the resources necessary to implement meaningful climate change policies.” (NIRS, n.d.). Greenpeace USA opposes nuclear power on environmental grounds, but argues also that its expense and its safety hazards are excessive (Leonard, 2015). According to Greenpeace, nuclear power plants are subject to inevitable “design and operator errors, and the threat of terrorist attacks” (Leonard, 2015).

Because nuclear power emits no carbon dioxide, the Union of Concerned Scientists (UCS), cautiously defends it. UCS admits nuclear power’s disadvantages, but argues that “Preserving the capacity of safely operated nuclear plants or ensuring that this capacity is replaced with zero carbon alternatives is an imperative that cannot be ignored” (Kimmell, 2018). UCS supports nuclear power only when it can be supplied safely and economically. The American Nuclear Society supports nuclear power for its relatively consistent, high-energy output. According to ANS: “Of all low- or zero-carbon energy sources, nuclear energy is by far the most energy dense ... . Nuclear energy can generate the same amount of electricity as solar on a third of the land, as wind on a fifth of the land, and as hydroelectric on a twentieth of the land” (ANS, 2020).

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