Rare-earth elements extraction from municipal solid waste incineration bottom ash by Electrodialytic Process

Huilin Li, Lisbeth M. Ottosen

Department of Environmental and Resource Engineering, Technical University of Denmark, Copenhagen, Lyngby, 2800, Denmark

Presenting author email: huilli@dtu.dk

Keywords: Electrochemical treatment; Municipal solid waste; Wastes to resources; rare-earth elements recovery

1. Introduction

Rare earth elements (REEs) are vital materials in modern technology, playing a crucial role in industries such as clean energy, electronics, and advanced manufacturing. For example, key elements like neodymium (Nd), praseodymium (Pr), and dysprosium (Dy) are essential for producing high-performance permanent magnets used in wind turbines and electric vehicles [1]. As the global transition to renewable energy and electrification accelerates, the demand for REEs is expected to increase significantly, highlighting the need for a stable and sustainable supply. However, the REEs supply chain faces challenges due to limited natural resources and complex geopolitical dynamics [2]. Moreover, traditional mining and refining methods often cause substantial environmental and social impacts [3]. In response, recycling REEs from secondary sources has emerged as a promising, more sustainable approach. Municipal solid waste incineration bottom ash (MSWI BA) is one of the potential secondary sources of these valuable elements [4]. The electrodialytic (ED) process, a membrane-based technique that uses an electric field to move ions through ion exchange membranes, has shown potential for efficiently extracting valuable materials from waste. For instance, Lima et al. demonstrated that up to 40% of REEs could be extracted from coal fly ash using citric acid, with a recovery rate of 148 g of REEs per ton of ash and an energy consumption of only 70 Wh per 100 g of treated material [5]. The ED process has thus emerged as a clean and efficient method for waste valorization. Despite the success of electrochemical techniques in metal extraction, the use of ED for REE recovery from MSWI BA remains underexplored.

2. Materials and methods

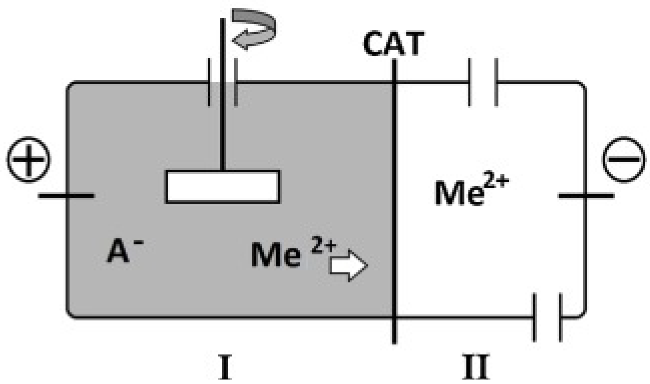

Figure 1. Diagram of the electrodialytic setup, where CAT is the cation exchange membrane, A-anion, Me-metal [6].

The MSWI BA sample was obtained from the Argo waste incineration plant in Roskilde, Denmark. The electrodialytic (ED) cell consisted of two compartments (I and II), where 50 g of bottom ash was suspended in 350 mL of distilled water in Compartment I, while Compartment II contained 500 mL of $NaNO_3$ as the electrolyte (as shown in Fig. 1). Both compartments were cylindrical, with an internal diameter of 8 cm, and constructed from Plexiglas. Compartment I measured 10 cm in length, while Compartment II was 5 cm long. A cation exchange membrane (from MKSUEZ Water Technologies & Solutions) separated the two compartments. Platinum-coated titanium electrodes were used for the experiment. To maintain the bottom ash suspension, a flexible plastic flap attached to a glass rod was connected to an overhead stirrer (VWR VOS-45W) and placed in Compartment I. A Hewlett Packard E3612A power supply provided a constant current. The MSWI BA suspensions were subjected to direct electric currents of 10 mA, 30 mA, and 50 mA for 14 days. Additionally, in a separate 50 mA experiment, the electrolyte was gradually pumped out from the cathode chamber to better regulate pH levels and prevent the deposition of REEs around the cathode.

3. Results and discussion

Initially seen as a waste management challenge, MSWI ashes have been found to accumulate REEs due to the concentration effect caused by incineration. Given their high boiling points (1194 - 3426°C), REEs tend to remain in BA rather than volatilizing during combustion. The concentrations of all detected REEs exceed those found in the Earth's crust, with lanthanum (La) reaching levels over 50 times higher. Pr and Nd, both essential for permanent magnet production, are enriched by factors of more than 30 and 20, respectively. These concentrations are comparable to those in other secondary sources, such as coal fly ash, phosphor gypsum, and mine tailings. While MSWI BA contains lower REE concentrations than primary deposits like hard rock ores and ion adsorption clays, its continuous and large-scale production makes it a promising alternative feedstock for REE recovery. The ED experiments showed that increasing the current from 10 mA to 30 mA significantly improved the extraction of all REEs. After the ED process, among the tested elements, Nd exhibited the highest extraction rates, exceeding 90% while using 50 mA. In contrast, REEs like scandium (Sc), and europium (Eu) consistently showed lower extraction rates under all conditions. The pumping of electrolytes benefits the ED system's stability and less REE deposition around the cathode by improving pH condition maintenance when applying 50 mA with slightly superior performance across many elements.

4. Conclusions and perspectives

MSWI BA has demonstrated potential as a secondary source of REEs, and the ED process offers a straightforward and effective method for their recovery. However, further research is needed to better understand the distribution, speciation, and release mechanisms of REEs in MSWI BA. Additionally, optimizing electrochemical parameters is crucial to improving REE extraction efficiency and maximizing recovery yields.

References

(1) Goodenough, K. M.; Wall, F.; Merriman, D. The Rare Earth Elements: Demand, Global Resources, and Challenges for Resourcing Future Generations. Natural Resources Research 2018, 27 (2), 201–216. https://doi.org/10.1007/s11053-017-9336-5.

(2) Dushyantha, N.; Batapola, N.; Ilankoon, I. M. S. K.; Rohitha, S.; Premasiri, R.; Abeysinghe, B.; Ratnayake, N.; Dissanayake, K. The Story of Rare Earth Elements (REEs): Occurrences, Global Distribution, Genesis, Geology, Mineralogy and Global Production. Ore Geol Rev 2020, 122 (April), 103521. https://doi.org/10.1016/j.oregeorev.2020.103521.

(3) Massari, S.; Ruberti, M. Rare Earth Elements as Critical Raw Materials: Focus on International Markets and Future Strategies. Resources Policy 2013, 38 (1), 36–43. https://doi.org/10.1016/j.resourpol.2012.07.001.

(4) Wen, Y.; Hu, L.; Liu, P.; Wang, Q.; Garcia, E.; Yan, W.; Tang, Y. Rare Earth Element (REE) Speciation in Municipal Solid Waste Incineration Ash. *Applied Geochemistry* **2025**, *178* (November 2024), 106239. https://doi.org/10.1016/j.apgeochem.2024.106239.

(5) Lima, A. T.; Ottosen, L. M. Rare Earth Elements Partition and Recovery During Electrodialytic Treatment of Coal Fly Ash. J Electrochem Soc 2022, 169 (3), 033501. https://doi.org/10.1149/1945-7111/ac56a6.

(6) Kirkelund, G. M.; Jensen, P. E.; Ottosen, L. M.; Pedersen, K. B. Comparison of Two- and Three-Compartment Cells for Electrodialytic Removal of Heavy Metals from Contaminated Material Suspensions. J Hazard Mater 2019, 367 (September 2017), 68–76. https://doi.org/10.1016/j.jhazmat.2018.12.063.

Acknowledgments

The authors would like to acknowledge that the research was funded by the European Union as part of the project " Integration of Underutilized Ashes into Material Cycles by Industry-Urban Symbiosis (AshCycle)".