

Editorial

Editorial for Special Issue “Leaching of Rare Earth Elements from Various Sources”

Kenneth N. Han 

Materials and Metallurgical Engineering, South Dakota School of Mines & Technology,
Rapid City, SD 57701-3995, USA; kennethhydro@gmail.com

Rare earth elements (REEs) have become an important group of metals used in many high-tech industries, including high-strength magnets, plasma TVs, various military applications, and clean and efficient green energy industries. Unlike many commercially available metals, REEs are rarely concentrated in mineable ore deposits. The principal concentrations of REEs are associated with uncommon varieties of igneous rocks, alkaline rocks, and carbonatites [1,2]. As the urgent need and demand for REEs to fuel the high-tech industries are growing, and relatively REE-rich ore deposits are getting depleted, there have been considerable efforts in identifying low-grade ores, and also the possible recovering of REEs from recycling resources. These sources include clay minerals, and coal and coal byproducts, especially in the eastern United States [3,4]. There have been attempts made to recover REEs from wasted used magnets and other recycling streams [5].

Most of the traditional deposits containing REE-bearing minerals are refractory in nature due to the unusually strong binding energies of these metals with the surrounding media. As a result, the strategy involving the extraction of these elements requires careful consideration of the chemical and physical nature of the energy associated between these metals and the surrounding media [6,7].

This Special Issue carries some important findings from the most current investigations into the leaching of REEs from various sources. There are 10 papers grouped into four categories: 1. Leaching from low-grade ores including coal, clay, soil, and red mud; 2. Pre-treatment and leaching; 3. Recycling; and 4. Precipitation and nano-hydrometallurgy. Four papers are dedicated to low-grade ores, such as coal and its derivatives, clay minerals, soils, and red mud. The grade of the REEs of some of these ores ranges from 200 to 1000 ppm, with some remarkable advantages, including the easy leaching ability due to the simple ion-exchange mechanism [8,9]. Zhang et al. [8] described a comprehensive literature survey with relevant scientific and technological discussions. They covered a vast amount of literature on the recovery of REEs from coal-based sources, including coal refuse, coal combustion ash, and acid coal mine drainage. Some process flowsheets integrating various technologies, such as physical beneficiation, acid leaching, pre-leach roasting, and hydrothermal pretreatment, have been designed, and some of these have been tested at bench scale. High-purity rare earth concentrates have been successfully produced from coal refuse and acid coal mine drainage. A rare-earth pilot plant was also constructed and tested, enabling the continuous production of REEs from coal refuse.

Montrose et al. [10] investigated the leaching behavior of REEs from a coal seam underclay using an organic acid and in combination with inorganic acids. Some of the underclay associated with coal seams in the Lower Freeport, Middle Kittanning, and Pittsburgh formations contain REEs at 250–457 ppm. Clay minerals such as illite, halloysite, and kaolinite make up >55% of the total bulk mineralogy of the rock. Organic acid and ammonium sulfate are often used for clay-type minerals, whereon the leaching is carried out through the ion-exchange mechanism. However, the current coal seam clay materials seem to contain REEs mainly as refractory REE-phosphates, and therefore, only the partial recovery of REEs was possible. Chaikin et al. [11] made an attempt to improve the extraction



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of REEs from an intermediate product of the bauxite sintering process, especially from the electrostatic precipitator dust, and have concluded that the best results were obtained by a double leaching process of leaching first at 95 °C, and then again at 240 °C.

Most of the REE-bearing minerals are refractory in nature, and therefore, in order to extract REEs from them it is necessary to increase the acidity, or they have to be subjected to pre-treatment with lixiviants such as sulfuric acid or sodium hydroxide before subjecting them to leaching. Kim et al. [12] attempted to control the amounts of additives in the heat-treatment to optimize the effectiveness of the pre-heating process. Others have also attempted pre-heating before leaching [8,13]. Xiao et al. [13] attempted alkaline fusion at 900 °C, resulting in a better than 95% recovery of scandium in the subsequent leaching.

A future trend in recovering REEs from valuable resources involves recovering them from wasted products. Sarfo et al. [14] attempted to recover Nd, Pr, and Dy from rare earth magnets by sulfuric acid leaching, followed by the precipitation of these REEs by ammonium hydroxide and ammonium bifluoride. Preferential precipitation of the dissolved REEs from the leach liquor can be a key to the success of the overall leaching process. Researchers have demonstrated the effective precipitation of REEs using various precipitants [15,16]. The effect of the anions present in the leach liquor has been found to be significant in the precipitation process. For example, anions such as Cl^- , NO_3^- , and SO_4^{2-} derived from acids used in the leaching process display a significant effect on the precipitation [15]. Watts and Leong have hypothesized that the distribution coefficient, λ , may be approximated from thermodynamic terms, including the solubility product (K_{sp}) of each rare earth oxalate and the stability constant (β_1) for the mono oxalato complex of each rare earth. The proposed model was used to calculate λ between pairs of rare earths [16]. Melo et al. [17] introduced magnetic nanohydrometallurgy to separate REE-ions using nano-sized iron oxide particles functionalized with ethylenediaminepropylsilane and diethylenediaminepentatcetic acid under a super magnetic field.

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