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Rare earth elements-A review of exploration, processing, environmental impact, recycling and prospect analysis

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Abstract. In high-tech and low-carbon economies, rare earth elements are becoming increasingly important. Global demand for REEs is increasing as society transitions to a more sustainable model with the goal of reducing reliance on fossil fuels. The study on rare earth elements (REEs) is reviewed in this document, including estimations of the world's reserves, categorization of REE deposits, key REE production paths and processing techniques, environmental effects, and the possibility for recycling in the rare earth business. This paper's main goal is to present a comprehensive environmental and socioeconomic perspective on REEs, emphasizing the environmental effects of various REE-related activities and looking at how REEs can be used more effectively and scientifically, such as by investigating the viability of recycling REEs. and offer an outlook for the future. In order to address the issues with their demand and lower the dangers involved with supplying rare earths, researchers are further developing the methods for mining and using rare earth elements as well as recycling and reusing them.

Keywords: REES, mineral deposit, processing method, environment impacts, recycling.

1. Introduction

The group of chemical elements referred to as rare earth elements (REEs) in the periodic table consists of seventeen compounds, namely yttrium, scandium, and the fifteen lanthanides as classified by the International Union of Pure and Applied Chemistry (IUPAC). Scandium and yttrium are classified as rare earth elements due to their tendency to co-occur in deposits alongside the lanthanides, as well as their possession of comparable chemical characteristics. Rare earth elements are becoming increasingly significant in various emerging energy technologies and systems aimed at mitigating greenhouse gas emissions and reducing reliance on fossil fuels. These elements possess distinctive physical and chemical characteristics, making them suitable for applications in wind turbines, electric vehicles, efficient lighting, batteries, and hydrogen storage. Consequently, the significance of the rare earth business has experienced a substantial surge in recent years. The industry in question has emerged as a significant force with profound implications for both the environment and the economy.

Nevertheless, it is well acknowledged that the extraction and manufacturing processes involved in the manufacture of rare earth elements (REEs) are not environmentally sustainable. This is mostly due to the substantial quantities of materials and energy required, coupled with the significant release of air and water pollutants, as well as the generation of substantial amounts of solid waste. Thus far, the

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extent of scholarly inquiry into the creation of rare metals has been considerably restricted. The global production of Rare Earth Elements (REEs) is expected to witness an increase due to the ongoing advancements in renewable energy and energy-efficient technology. This will also give rise to more inquiries on rare earth elements (REEs).

Therefore, this paper focuses on the past, present and future of rare earth elements, their environmental impact and corresponding improvement measures, as well as their future development direction.

This research describes the diverse methods of mining rare earth elements, how to improve their utilization, and future directions, revealing that the hazards of utilizing rare earths can be artificially reduced.

2. REE exploration status and deposit types

At present, the total rare earth reserves in prominent nations such China, Brazil, Vietnam, Russia, and India amount to approximately 130 million tons. The aforementioned resources originate from four primary geological environments, namely carbonates, alkaline igneous systems, ion-adsorbed clay deposits, and monazite-containing cactus deposits. China possesses around 33% of the global deposits of rare earth resources, hence maintaining its position as the foremost global leader in the exploration and production of such materials [1].

While rare earth elements are found in very high quantities in the earth's crust, they are not typically found in concentrated deposits that can be economically extracted, which sets them apart from most other metals. REE deposits have the potential to be categorized into primary and secondary deposits. Primary deposits are geological formations that result from the processes of magmatism, hydrothermal activity, and/or metamorphism. The aforementioned deposits exhibit a prevalent association with alkaline igneous and carbonate rocks, and their deposition can be attributed to an extensional geological setting. Secondary deposits are geological formations that arise from the processes of erosion and weathering. These deposits encompass a variety of mineral resources, such as ore deposits, laterites, and bauxites. REE deposits can be further classified under the two aforementioned groups depending on their genetic links, mineralogy, and mode of occurrence. Due to the occurrence of rare earth element (REE) deposits in diverse geological environments, their classification into distinct categories poses a challenge. Categorizing them into distinct classifications poses a challenge. Sowerbutts categorized economically valuable deposits of rare earth elements into four distinct classifications. Nevertheless, considering the substantial abundance of these elements in coal and marine sediments, REE deposits can also be categorized into the subsequent five classifications: The types of geological formations that are associated with the occurrence of rare earth elements (REE) include: (i) alkaline igneous rocks, namely pegmatites and carbonates; (ii) residual deposits; (iii) heavy mineral deposits; (iv) REE found in coal; and (v) REE found in continental shelf sediments [1]. In the present day, numerous nations have initiated comprehensive research endeavors aimed at identifying and analyzing rare earth deposits by geological, geophysical, geochemical, and mineralogical methodologies.

3. Mining methods and separation and purification of rare earth elements

The conventional extraction and refinement methods employed in the mining and processing of rare earth elements necessitate substantial quantities of energy, water, and chemical substances. After the rocks containing rare earth elements undergo the process of crushing and grinding, they are subjected to enrichment using beneficiation techniques, such as X-ray sorting, magnetic or gravity separation, and flotation. The extraction of rare earth element (REE)-containing minerals is a complex process due to the wide range of minerals that include REEs and the relatively low concentrations of REEs in geological formations. Consequently, the leaching methods employed for extracting these minerals can be categorized into four primary groups: alkaline leaching, acidic leaching, chlorination, and ion exchange. There are two main types of mining methods: physical and chemical methods. The physical methods mainly include ion exchange methods, extraction methods, solvent extraction methods, high temperature electrolysis methods, ion injection methods, etc. Chemical methods mainly include pyrometallurgy and hydrometallurgy. The content of rare earth elements in nature is very low, so process technology is needed to separate them out and then purify them. Commonly used rare earth separation and purification methods include: extraction, precipitation, ion exchange, membrane separation, solvent extraction and evaporation and crystallization. It is feasible to obtain high purity rare earth products through the separation of rare earth elements. In the production of rare earth metals or oxides, high purity products can be obtained by using the above methods, such as increasing the purity of rare earth oxides from 90%~95% to more than 99.95%~99.9%. Since rare earth is a kind of metal that is insoluble in water, diluents is generally added in the separation process to dissolve rare earth elements in solution, and then further separated to obtain high purity products.

The present mining and processing procedures commonly exhibit suboptimal recovery rates, typically ranging between 50% and 80% when converting ore into high purity rare earth compounds. The suboptimal recuperation can be attributed, in part, to the relatively diminished inherent worth of the geological resource in relation to the expenses incurred during the processing phase. In the present study, novel findings are presented that elucidate strategies for enhancing recoveries through the advancement of potent and specific reagents, streamlined concentration units, and comprehensive models for the integration of processing flow sheets. Despite ongoing efforts to enhance the processing of rare earth elements by evaluating and implementing more advanced flotation reagents and solvent extractants, the resulting advantages are very minor. The study places emphasis on the utilization of several methodologies, such as ionic or molecular separation, which encompass microporous hollow fiber contactors, emulsion-liquid membrane extraction, and molecular recognition technology (MRT). Several approaches that can be employed in this context include electrically enhanced extraction, phase change extraction, solvents with tunable properties, ionic liquids, deep eutectic solvents, and miniaturized extraction [2]. These are the corresponding improvements.

4. Environmental impacts of rare earth production and improvement measures

The utilization of rare earth elements is integral to numerous clean energy sources; yet, the extraction and production processes associated with these elements can yield significant environmental consequences. A prevailing difficulty pertaining to the mining and processing of rare earth elements is the presence of thorium (Th) and uranium (U) in relatively low amounts among ionic clays found in all rare earth deposits. The availability of on-site disposal solutions is frequently constrained and governed by stringent rules, whilst the transportation and confinement of waste in public landfills is prohibitively costly or unfeasible. If not properly controlled, the presence of radioactive materials might potentially endanger human health, particularly through the breathing of dust that has been polluted [2].

During the development and application of rare earth elements, harmful substances may be produced that pollute the environment. For example, rare earth oxides are used in large quantities to manufacture products such as plastics, glass and ceramics, but during the manufacturing process, a large amount of harmful substances, such as formaldehyde and benzene, may be produced. The main hazards of rare earth oxides come from the toxicity and radioactivity that rare earth oxides they possess [3].

The incorporation of environmental sustainability as a fundamental metric within the framework of a circular economy model for rare earths is warranted, owing to the substantial ecological consequences and energy demands associated with the extraction processes involved in rare earth mining. According to the United States Environmental Protection Agency (EPA, 2012), it is advised to employ environmental management systems in order to ascertain the origins, routes, and ultimate destiny of pollutants inside industries associated with rare earth materials. Hence, the establishment of a rare earth circular economy framework, encompassing elements such as eco-design methodologies, urban mining strategies, rare earth ecosystem value chain modeling, and life cycle evaluation, will yield environmental advantages [4].

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At present, the prevailing method for evaluating environmental sustainability is Life Cycle Assessment (LCA). In recent times, Life Cycle Assessment (LCA) has emerged as a pivotal instrument for facilitating sustainable product creation and informing environmental policy decisions for both corporate entities and governmental bodies on a global scale. In summary, life cycle assessment (LCA) adopts a comprehensive methodology that offers a comprehensive understanding of the environmental consequences associated with a process or product across its entire life cycle. This encompasses various stages such as the extraction and procurement of raw materials, manufacturing, transportation and distribution, utilization and maintenance, as well as potential opportunities for reuse and recycling, culminating in disposal and waste management [5].

5. Recycling rare earth elements and prospects

The emphasis on recycling rare earth elements (REEs) is driven by the escalating demand for these elements. Exploration of rare earth element (REE) ore refinement is currently being undertaken in many global regions as a means to address escalating demand and mitigate supply vulnerability. Various processing routes might be employed based on the content of the ore. There are ongoing endeavors to enhance the technology used for processing rare earth elements (REEs) and to increase the recovery of these elements.

The recycling and reutilization of rare-earth goods at the end of their life cycle entail considerable energy consumption and intricate procedures. The recycling process of rare earth products is intricate due to the presence of minimal quantities of rare earth elements in recyclable or reusable materials, which subsequently hampers the performance of the recycled material [6].

In general, the recycling process usually involves four key steps: collection, disassembly, separation, and processing. The first three steps involve physical processing (e.g., collection, manual or mechanical separation, shredding, and screening), while the last step requires more engineering skills (e.g., pyrometallurgy, hydrometallurgy, and electrometallurgy) [4].

The sources of secondary rare earth elements (REEs), which serve as the primary materials for REE recovery, can be categorized into three principal groups: secondary mining materials (such as tailings and residues), coal and coal combustion products (namely ash), and by-products derived from apatite and phosphate mines. Tailings and other byproducts of mining operations have the potential to include rare earth elements (REEs), which can serve as a significant reservoir of these valuable resources. Furthermore, it is worth noting that the concentration of rare earth elements found in coal and coal combustion products has the potential to reach or surpass that of traditional rare earth ores. Consequently, the extraction of rare earths from coal and coal ash for the purpose of obtaining rare earth elements will likely become feasible in the future. The recovery of end-of-life products may play a crucial role in addressing the issues related to the supply of rare earth elements and enhancing their flow efficiency, owing to the diverse variety of uses associated with these elements. Nevertheless, the current recovery rate for rare earth elements from end-of-life items is merely 1%, resulting in the remaining percentage being disposed of in landfills, so effectively eliminating their potential for reintegration into the materials cycle [4].

6. Conclusion

This paper introduces the status quo of rare earth element exploration and deposit types, mining methods, separation and purification, the impact of rare earth production on the environment and improvement measures, recycling, and the prospects of rare earth elements.

It is highly probable that rare earth elements will continue to hold significant importance in our future. They are an important part of our manufacturing of various defense, aerospace, industrial and consumer electronics. At the same time, these metals can help combat climate change and global warming, reduce greenhouse gas emissions, and avoid climate collapse. That's why a comprehensive exploration effort is necessary. In addition to mining on land, there are options such as deep-sea mining and extracting these metals from coal dust or for secondary use. In this way, the pressure on the mining industry and the environment will be reduced. At the same time, there is a great need to

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develop sustainable mining plans for the various rare earth deposits and strictly follow them to prevent further environmental damage.

While rare earth elements (REEs) provide a substantial contribution to the sustainability of energy, their manufacturing is characterized by high energy and material requirements, as well as severe pollution. Given the escalating demand for Rare Earth Elements (REEs), it is imperative to develop a thorough comprehension of the environmental consequences associated with the manufacturing of these elements. LCA assessment of environmental sustainability is the most widely used method. Nevertheless, there is a scarcity of Life Cycle Assessment (LCA) research pertaining to the manufacturing process of Rare Earth Elements (REEs). This study only illustrates a few aspects of research on rare earth elements and does not and has no way to finish the whole problem of rare earth. However, we should focus on using LCA methods in the future to advance sustainable development.This is a huge benefit to the entire human community and the world.

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