Analysis of the Comprehensive Utilization Efficiency of Secondary Resources of New Rare Earth Materials Based on Regeneration Technology

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Keywords: New rare earth materials; Secondary resources; Regeneration technology; Efficiency optimization

Abstract: New rare earth materials are high-end, with crucial strategic value and broad application prospects. However, a large amount of rare earth waste will be produced in production and use, resulting in a waste of resources and environmental pollution. This paper proposes a rare earth recovery model based on regeneration technology to realize the comprehensive utilization of secondary resources of new rare earth materials, and the efficiency and benefit of rare earth recovery are optimized. First, we analyze the task description and structure of the traditional rare earth recovery model. Second, the multi-objective optimization and the fuzzy function substitution optimization are introduced, and the improved rare earth recovery model structure is designed. Third, this article introduces the principles and methods of regeneration technology, analyzes the main problems and challenges, and establishes an effective optimization model and algorithm based on multi-objective optimization, fuzzy function, and improved bee algorithm. Finally, we summarize the main contents and conclusions of this paper and put forward the future research direction.

1. Introduction

New rare earth materials are high-end materials with strategic value and broad application prospects. However, during the production and use process, a large amount of rare earth waste will be generated, causing waste of resources and environmental pollution. Therefore, we need to explore a rare earth recovery model based on regeneration technology to realize the comprehensive utilization of secondary resources and improve the utilization efficiency and environmental benefits of rare earth resources. Regeneration technology uses physical, chemical, or biological methods to recover rare earth metals or compounds from rare earth waste and prepare new rare earth materials. Regeneration technology can not only save rare earth resources and reduce external dependence but also reduce the cost of rare earth materials and improve their competitiveness. At the same time, it can reduce the impact of rare earth waste on the environment and achieve green and recycling development. However, the regeneration technology also faces some challenges and problems, such as the separation and pretreatment of rare earth waste, the extraction and separation of rare earth metals, and the re-preparation and performance evaluation of new rare earth materials. Therefore, how to optimize the efficiency and benefit of regeneration technology is an urgent scientific problem to be solved.

Based on the above background analysis, this paper proposes a rare earth recovery model based on regeneration technology to optimize the efficiency and benefit of rare earth recovery. This paper analyzes the task description and structure of the traditional rare earth recovery model. Then, it introduces multi-objective optimization and fuzzy function optimization to design an improved rare earth recovery model structure. In addition, this paper introduces the principle and method of regeneration technology, analyzes the critical problems and challenges of the technology, and establishes the efficiency optimization model and algorithm based on multi-objective optimization, fuzzy function, and improved bee algorithm. Finally, it summarizes the main contents and conclusions of this paper and puts forward the future research direction. The research content of this paper provides a new idea and method for the comprehensive utilization of new rare earth materials and secondary resources, which effectively copes with the shortage of rare earth resources and

  DOI: 10.25236/icmmct.2024.021

environmental pollution and has significant theoretical and practical value.

2. Traditional Rare Earth Recovery Model

2.1 Task Description of Comprehensive Utilization of Secondary Resources of New Rare Earth Materials

The task description of comprehensive utilization efficiency of secondary resources of new rare earth materials refers to how to evaluate and improve the utilization efficiency and environmental benefits of rare earth resources in the process of recycling, reuse, and repreparation of rare earth waste generated in the production and use [1]. New rare earth materials refer to new materials with excellent functions or properties prepared by utilizing the unique properties of rare earth elements or their compounds, such as rare earth permanent magnet materials, rare earth luminescent materials, rare earth catalytic materials, etc. Secondary resources of new rare earth materials are waste or by-products containing a certain amount of rare earth elements or their compounds formed during the production and use of new rare earth materials, such as rare earth magnet waste, rare earth phosphor waste, and rare earth catalyst waste. The overall secondary resource utilization efficiency of new rare earth materials refers to the economic achievement, high efficiency, and recycling of rare earth resources to reuse and recycle secondary resources. At the same time, it reduces environmental pollution and improves the comprehensive index of economic and social benefits [2].

2.2 Rare Earth Recovery Model Based on Regeneration Technology

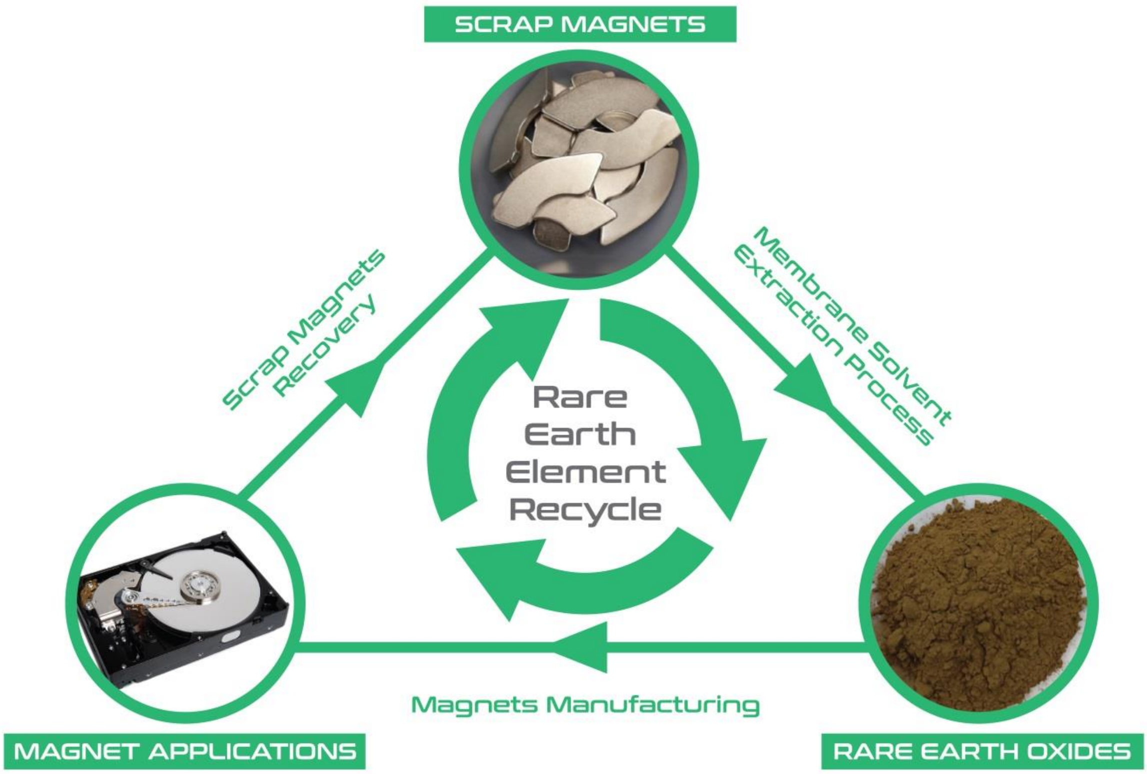

Figure 1 The rare earth recovery model architecture based on regeneration technology

The rare earth recovery model based on regeneration technology refers to recovering, reusing, and re-preparing the secondary resources of new rare earth materials by regeneration technology, which aims to optimize the efficiency and benefits of rare earth recovery. Regeneration technology is a technology that uses physical, chemical, or biological methods to recover rare earth metals or compounds from rare earth waste and prepare them into new rare earth materials. Regeneration technology and traditional rare earth recovery technology discuss the definition of rare earth recovery from multiple perspectives, including principles, methods, and effects [3]. Some scholars believe that regeneration technology is the upgrading of rare earth recovery technology or rare earth recycling technology. Because regeneration technology is more innovative and sustainable to some extent, it is an advanced science for green development. The development history of regeneration technology can even be traced back to the 1980s. Its principal activities include the recycling and reusing of rare earth magnets, phosphors, and catalyst wastes. In addition, the concept and practice of regeneration technology are closely related to China's rare earth resource strategy and policy. The implementation of rare earth resource protection and management has improved the utilization efficiency of rare earth resources and promoted the transformation and upgrading of the rare earth industry. High-tech has become important for comprehensively utilizing secondary resources of new rare earth materials in China [4]. Since the new century, China has made remarkable progress in regeneration technology. The main contribution is to establish a complete system, covering all aspects from waste separation and pretreatment to rare earth extraction and separation to new material preparation and performance evaluation. Therefore, the rare earth recovery model based on regeneration technology initially focused on the efficiency measurement based on the standard attributes of material flow. The rare earth recovery model architecture based on regeneration technology is shown in Figure 1.

3. Improved Rare Earth Recycling Model Structure

3.1 Introducing Multi-objective Optimization

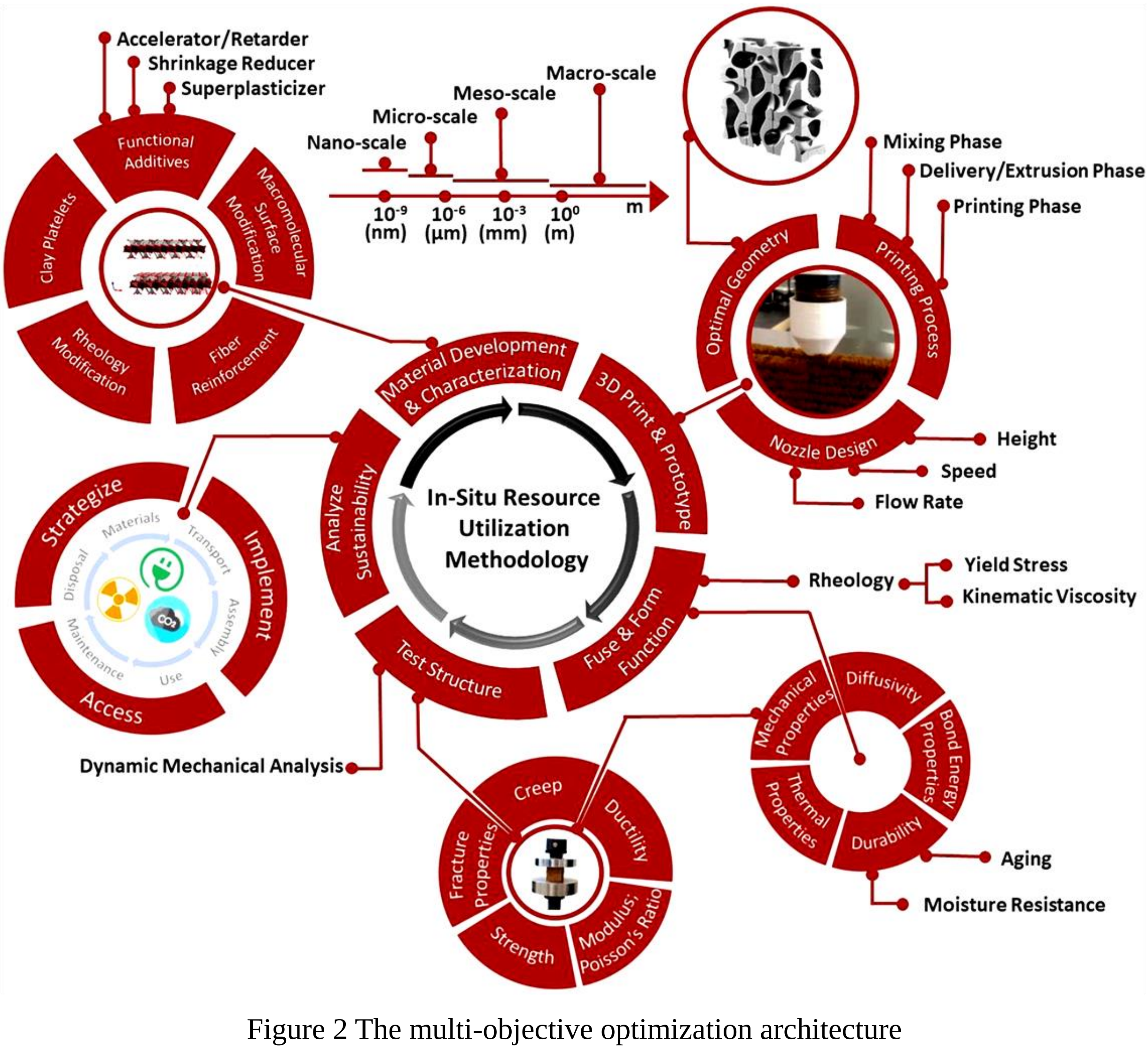

Figure 2 The multi-objective optimization architecture

Compared with the traditional model, the improved rare earth recovery model emphasizes the relationship between the efficiency and benefit of rare earth recovery and has the characteristics of multi-objective optimization. Although some scholars question that there may be no direct relationship between the efficiency and benefits of rare earth recycling, most believe that efficiency can rationally evaluate benefits. Li et al. proposed a classic efficiency-benefit model for rare earth recycling that includes four elements: resource utilization, environmental impact, economic cost, and social benefit. Since then, the model has become a typical tool for rare earth recovery, introducing the multi-objective optimization concept. These scholars believe that efficiency is multidimensional and a "comprehensive performance indicator." Rare earth recovery will be highly efficient and effective when resource use, environmental impact, and economic costs are optimized, and social benefits are maximized. Therefore, benefit is closely related to efficiency. In addition, scholars have summarized multi-objective optimization into two models, including the efficiency-benefit model based on the weight method and the efficiency-benefit model based on the fuzzy function. The former focuses on determining the weight of each target, and the latter focuses on dealing with the uncertainty of each target. Although multi-objective optimization has experienced some practical difficulties, from a theoretical point of view, it considers all aspects of rare earth recovery, so the multi-objective optimization concept has gradually become the consensus of research and practice to improve the model structure [5]. The multi-objective optimization architecture is shown in Figure 2.

3.2 Fuzzy Function

This section presents the use of fuzzy functions to resolve uncertainties and ambiguities in rare earth recovery models [6]. Fuzzy function is a mathematical tool based on fuzzy set theory, which can describe imprecise or incomplete information. To overcome the shortcomings of the traditional rare earth recovery model, it has entered the research field as an alternative model-fuzzy optimization framework. The basic idea of the framework is as follows. First, rare earth recycling should ensure the improvement of efficiency and benefits. Second, set professional standards for rare earth recycling. Third, capture the uncertainty and ambiguity in the rare earth recycling process through techniques such as fuzzy sets. Fourth, the fuzzy function is used to measure the efficiency and effectiveness of rare earth recycling. Fuzzy optimization reconstructs the rare earth recovery model, highlighting the need to improve the flexibility of rare earth recovery and increase efficiency, feasibility, and robustness to adapt to uncertainty and ambiguity.

3.3 Initializing Fuzzy Set Function

This paper proposes an initialization fuzzy set based on fuzzy function. It uses the nonlinear mapping ability of the fuzzy function to transform the uncertainty and fuzziness in the rare earth recovery model into a problem of certainty. It realizes the accurate optimization of the efficiency and benefit of rare earth recovery by training the fuzzy function model. To verify the effectiveness of this method, we use MATLAB as the simulation platform to generate efficiency-benefit data of different types, locations, and scales of rare earth waste and use it as the input of the fuzzy function model. The simulation results show that the method can realize multi-objective optimization in complex environments and has good robustness and generalization ability. In addition, fuzzy function is a mathematical tool based on fuzzy set theory used to describe imprecise or incomplete information. The fuzzy function is expressed as follows:

$$y = f(x) = \sum_{i=1}^{n} w_i \mu_i(x) \tag{1}$$

Among them, y is the output variable, x is the input variable, n is the number of rules, w_i is the weight of the i-th rule, and $\mu_i(x)$ is the membership function of the i-th rule.

3.4 Structural Design of Improved Rare Earth Recovery Model

In the related research on the rare earth recovery model, the previous research considered the single-objective optimization of efficiency and ignored the multi-objective optimization. Therefore, the optimization effect of the model could be better. Based on the above problems, we have improved the structural design of the rare earth recovery model, mainly combining the fuzzy function and the improved bee algorithm model [7], and deeply optimized the traditional efficiency-benefit framework structure to optimize the efficiency and benefit of rare earth recovery. Specifically, firstly, the uncertainty and fuzziness in the rare earth recovery process are transformed into certainty by the fuzzy function, and the efficiency-benefit model based on the fuzzy function is established. Second, the improved bee algorithm trains and optimizes the fuzzy function model to find the best weight and membership function. Third, the trained fuzzy function model evaluates and optimizes the efficiency and benefit of rare earth wastes of different types, locations, and scales. Finally, the simulation experiment verifies the effectiveness and superiority of the improved rare earth recovery model structure design. The improved bee algorithm is an optimization algorithm based on natural heuristics, and its function is to obtain the optimal or approximately optimal solution. The function/model of the improved bee algorithm is expressed as follows:

$$f(x) = \min_{x \in S} f(x) \tag{2}$$

Among them, $f(x)$ is the objective function, x represents the decision variable, and S represents the feasible solution set. Structure design of improved rare earth recycling model is shown in Figure 3.

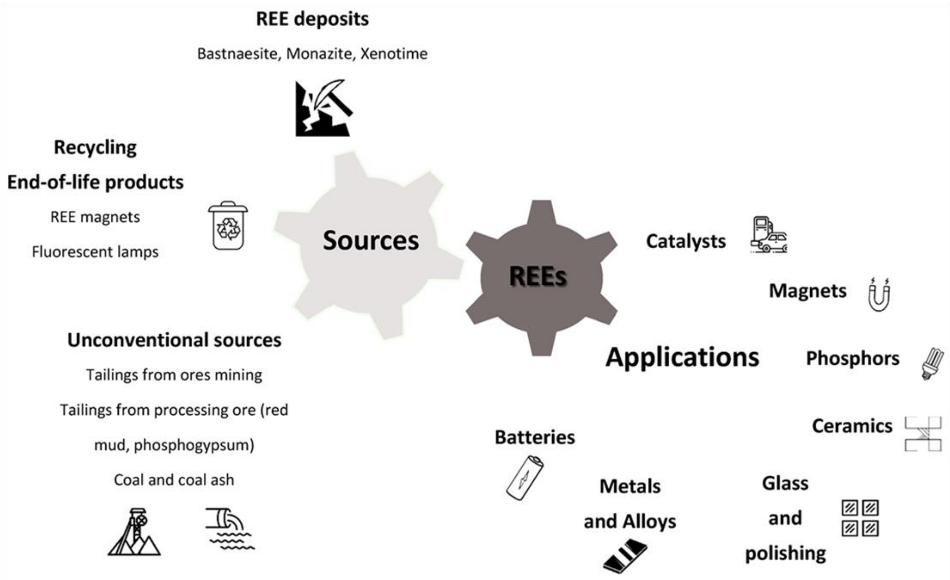

Figure 3 Structure design of improved rare earth recycling model

4. Efficiency Optimization of Rare Earth Recovery Based on Regeneration Technology

4.1 Principles and Methods of Regeneration Technology

From a recycling technology perspective, traditional rare earth recycling technology cannot produce the performance and efficiency required. The evaluation of rare earth recovery by new rare earth materials secondary resources is mainly in the form of efficiency-benefit. Still, the traditional rare earth recovery technology lacks relevant information and optimization mechanisms about efficiency and benefit. The core of this problem may be uncertainty and ambiguity. Uncertainty and ambiguity are often cited as factors influencing the rare earth recovery process, and the efficiency and benefits of rare earth recovery reflect the difficulty of rare earth recovery. However, most traditional rare earth recovery concerns material flow, energy consumption, and cost; the efficiency and benefit are low. Information asymmetry and incomplete evaluation criteria directly impede rare earth recycling.

4.2 Key Issues and Challenges of Regeneration Technology

From the perspective of regeneration technology, the technical difficulty and economic cost have restricted rare earth recovery for a long time. Since the 21st century, the regeneration technology integrating physics, chemistry, and biology has reshaped the mode of rare earth recycling through the recovery, reuse, and re-preparation of rare earth waste. However, the drawbacks of the traditional efficiency-benefit evaluation method restrict the optimization of the recovery method. Due to the contradiction between efficiency and benefit and the influence of uncertainty, the efficiency-benefit evaluation method of rare earth recovery needs to be improved. Under the premise of multi-objective optimization, the fuzzy function is regarded as a direct way to deal with the problem. However, the actual optimization effect of the efficiency-benefit evaluation method on rare earth recovery remains to be discussed. At the same time, the difficulty of fuzzy function training and optimization leads to the need for a more effective optimization algorithm for rare earth recovery. Therefore, scientists cannot consistently achieve the optimal goal of rare earth recovery efficiency and effectiveness. It turns out that regeneration technology is not just a technical issue but also issues with evaluation methods and optimization algorithms.

4.3 Efficiency Optimization Model and Algorithm of Regeneration Technology

The traditional rare earth recovery technology cannot be avoided as the 'influencing factor' of multi-objective optimization in efficiency and benefit. In the multi-objective optimization mechanism, the fuzzy function is a standard and effective evaluation tool for rare earth recovery. It also makes the fuzzy function a technical concept and an evaluation concept. Therefore, the fuzzy function based on efficiency-benefit becomes the optimization mechanism of rare earth recovery. The practice of an improved bee algorithm is generally an optimization path based on the fuzzy function, although this path contains uncertainty and ambiguity. The improved bee algorithm is closely connected with regeneration technology, from physics and chemistry to biology. We are committed to improving the utilization efficiency and environmental benefits of rare earth resources to meet the requirements of green development. However, when uncertainty and ambiguity are taken seriously, there is a dilemma: multi-objective conflict.

To sum up, the efficiency optimization model and algorithm of regeneration technology have room for improvement in weight determination and membership function selection. In addition, its optimization effect needs to be further improved, which is also one of the critical tasks of regeneration technology. The distribution results of the comprehensive utilization efficiency of rare earth are shown in Figure 4.

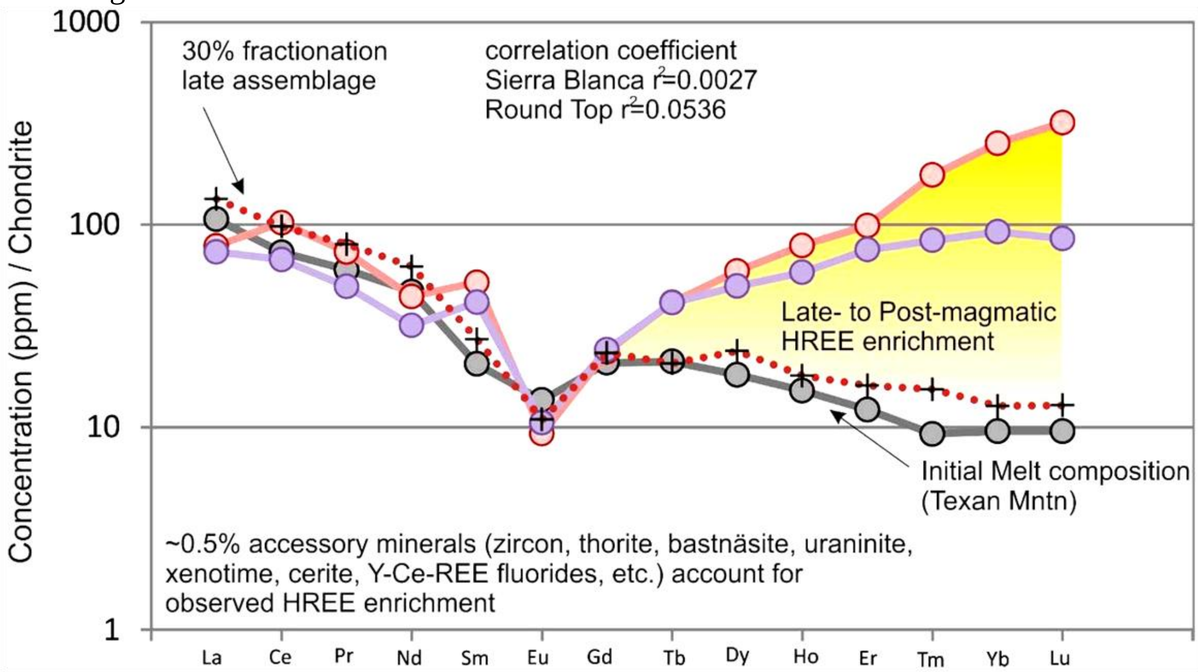

Figure 4 The distribution results of comprehensive utilization efficiency of rare earth

5. Conclusion

The comprehensive utilization efficiency of secondary resources has become a vital issue in developing the rare earth industry, which poses new challenges and requirements for protecting and managing rare earth resources. Regeneration technology represents innovation in rare earth recycling and is an important means of reprocessing new rare earths. There is an urgent need to achieve green development and protect national strategies. It reflects the inherent requirements of transforming and upgrading the rare earth industry. The rare earth recovery model based on regeneration technology is a theoretical analysis framework and practical mechanism for constructing rare earth recovery efficiency and benefit under the guidance of multi-objective optimization. In recent years, modern mathematical tools such as fuzzy functions have promoted the improvement of the model. The improved bee algorithm optimizes the rare earth recovery model, improving the accuracy of rare earth recovery efficiency and benefit. Its value fits the internal logic of regeneration technology. Therefore, regeneration technology also provides a new way for the comprehensive utilization of secondary resources of new rare earth materials. In conclusion, the sustainable improvement of regeneration technology will help better use rare earth resources and promote the green and circular development of the rare earth industry.

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