

JOINT INSTITUTE FOR NUCLEAR RESEARCH Frank Laboratory of Neutron Physics

**FINAL REPORT ON THE**

**INTEREST PROGRAMME**

*Application of biological adsorbents for industrial wastewater treatment*

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ABSTRACT

This internship report delves into the extensive literature surrounding the application of various adsorbents in the wastewater treatment process for the separation of rare earth elements (REEs) in both single and multi-component systems. Confronted by the inherent challenge of similar chemical properties among REEs, the study critically evaluates recent research advancements, emphasizing evolving separation technologies and a nuanced assessment of performance metrics. Employing a systematic literature review methodology, the report spans studies published over the last decade. Central to this exploration is the categorization of adsorbents, ranging from traditional ion-exchange resins to cutting-edge hybrid materials and activated carbon. Rigorous scrutiny of their respective efficiency and selectivity in the intricate process of REE separation provides a nuanced understanding of the landscape. The abstract concludes with insights into key trends, challenges, and opportunities, offering a valuable resource for researchers and industry professionals engaged in the critical domain of rare earth element separation. This exploration not only contributes to academic discourse but also establishes a foundation for informed decision-making and innovative advancements in the realm of REE separation. In future, this exploration of adsorbent technologies not only contributes to the academic discourse but also lays the foundation for informed decision-making and innovative advancements in the realm of REE separation.

Key words: Rare Earth Elements (REEs), Adsorbents, Separation, Selectivity

**1. Introduction:**

The extraction and separation of rare earth elements (REEs) constitute a pivotal challenge in the realms of materials science, chemistry, and industrial applications. REEs, comprising 15 lanthanides, scandium, and yttrium, are critical components in various advanced technologies, including electronics, green energy, and defense systems. Despite their ubiquitous presence in the Earth's crust, the inherent difficulty in isolating these elements arises from their strikingly similar chemical properties, necessitating sophisticated separation techniques.

**1.1 Main Problem:**

The main problem addressed in this literature review stems from the imperative need to devise effective and environmentally sustainable methods for separating REEs. With increasing global demand for REEs in applications ranging from consumer electronics to renewable energy technologies, ensuring a stable and efficient supply has become a critical concern. The challenge lies not only in overcoming the chemical similarities between different rare earth elements but also in developing separation processes that are economically viable and environmentally responsible.

**1.2 Background:**

Historically, the separation of REEs has been dominated by solvent extraction processes, ion exchange, and precipitation methods. However, these traditional approaches often suffer from drawbacks such as high operational costs, environmental impact, and low selectivity. Recent advancements in materials science and nanotechnology have paved the way for exploring innovative adsorption-based methods using various adsorbents.

**1.3 Findings:**

Current research findings highlight a diverse array of adsorbents showing promise in the separation of REEs. These materials range from traditional ion-exchange resins and activated carbon to more novel hybrid materials engineered for enhanced selectivity and efficiency. The pursuit of sustainable separation technologies is gaining momentum, reflecting the broader shift toward environmentally conscious practices in resource extraction and processing.

This literature review endeavors to synthesize and critically evaluate the existing knowledge on adsorbents for REE separation. By delving into the mechanisms, performance metrics, and advancements in separation technologies, this exploration aims to contribute to the understanding of the current state of REE separation methodologies. Furthermore, it sets the stage for identifying gaps in the current research landscape and proposing avenues for future investigations, emphasizing the crucial intersection of scientific innovation, economic feasibility, and environmental responsibility in the pursuit of sustainable rare earth element separation.

**2. Project Goals:**

The overarching goals of this internship project are strategically crafted to address the intricacies and challenges inherent in the separation of rare earth elements (REEs). Each goal is meticulously designed to contribute to the broader understanding of REE separation methodologies, with a focus on adsorbents in both single and multi-component systems.

**2.1 Critical Analysis and Compilation:**

The primary goal of this project is to undertake a comprehensive and critical analysis of existing research literature. This involves delving into a multitude of studies, including journal articles, conference papers, and research reviews published within the last decade. By assimilating this vast body of knowledge, the aim is to compile an exhaustive and up-to-date repository of information on various adsorbents employed in the separation of REEs. The critical analysis extends beyond mere aggregation, emphasizing the discerning evaluation of the methodologies, findings, and limitations of each study.

**2.2 Identification of Research Gaps:**

An intrinsic aspect of this internship project is to discern and identify gaps in the current research landscape pertaining to REE separation. By critically evaluating existing literature, the goal is to pinpoint areas where knowledge is either limited or lacking. This identification of research gaps is instrumental in directing future investigations, guiding researchers and industry professionals toward unexplored avenues that hold potential for groundbreaking advancements.

**2.3 Insights into Strengths and Limitations:**

Understanding the strengths and limitations of different adsorbents used in REE separation is a pivotal goal. This involves a nuanced analysis of the performance metrics of various adsorbents, including their efficiency, selectivity, and scalability. By gaining insights into the comparative advantages and disadvantages of different materials, the project aims to provide a well-rounded perspective for researchers and industry practitioners, enabling them to make informed decisions in the selection and optimization of separation methodologies.

**2.4 Emphasis on Single and Multi-Component Systems:**

A distinctive feature of this project is its explicit focus on both single and multi-component systems. While the similarities in chemical properties pose challenges in single-component systems, the complexity escalates in multi-component environments. The goal is to comprehensively address the intricacies of REE separation across these different scenarios, providing a holistic understanding of the challenges and advancements in each context.

**3. Scope of Work:**

The scope of this internship project is designed to be expansive and encompassing, aiming to provide a comprehensive overview of the landscape surrounding the separation of rare earth elements (REEs). The delineation of the scope is pivotal for guiding the methodology and ensuring the project's relevance and impact.

**3.1 Temporal Scope:**

The temporal scope of this project is defined to encapsulate recent developments in the field. The focus is on literature published within the last decade, ensuring the inclusion of contemporary studies that reflect the latest advancements in adsorbent technologies for REE separation. By confining the temporal scope, the project aims to capture the dynamic nature of research in this rapidly evolving field.

**3.2 Material Scope:**

Encompassing a broad range of materials, the scope includes traditional adsorbents such as ion-exchange resins and activated carbon, as well as emerging hybrid materials engineered for enhanced performance. This inclusivity allows for a nuanced exploration of the diverse array of adsorbents employed in REE separation. The project is structured to accommodate the chemical and structural intricacies of different adsorbents, ensuring a comprehensive understanding of their roles in the separation process.

**3.3 Focus on Mechanisms and Performance Metrics:**

The scope extends to the exploration of mechanisms employed by various adsorbents in capturing and separating rare earth elements. Understanding these mechanisms is crucial for deciphering the selectivity and efficiency of different materials. Additionally, the project emphasizes the quantitative assessment of performance metrics, including but not limited to separation efficiency, selectivity, and capacity. This focus ensures a robust evaluation of the practical utility of adsorbents in real-world scenarios.

**3.4 Single and Multi-Component Systems:**

Recognizing the multifaceted challenges in REE separation, the project's scope explicitly includes both single and multi-component systems. The intricacies of single-component systems, where the chemical similarities between REEs pose challenges, are juxtaposed against the heightened complexity of multi-component systems. By addressing both scenarios, the project aims to provide insights into the adaptability and limitations of adsorbents across diverse operational contexts.

**3.5 Holistic Overview:**

The project's scope extends beyond a mere compilation of information, aiming to provide a holistic overview of the challenges and advancements in the field. By incorporating the temporal, material, and operational dimensions, the project seeks to create a comprehensive narrative that not only informs but also guides future research endeavors in the realm of REE separation.

**4. Methods:**

The methodology employed in this internship project is designed to rigorously and systematically explore the diverse landscape of adsorbents used for the separation of rare earth elements (REEs). The chosen methods are intended to ensure the comprehensive collection, analysis, and synthesis of information from a multitude of sources.

**4.1 Systematic Literature Review:**

The cornerstone of the methodology is the implementation of a systematic literature review. This approach involves a meticulous and structured search across reputable databases, encompassing academic journals, conference proceedings, and research reviews. The search strategy incorporates relevant keywords such as "rare earth elements," "adsorbents," and "separation," ensuring a broad yet targeted selection of literature. The systematic nature of the review minimizes bias, enhances reproducibility, and facilitates the identification of key studies within the defined temporal scope.

**4.2 Inclusion Criteria:**

The application of stringent inclusion criteria is a pivotal aspect of the methodology. Articles considered for inclusion must specifically address the use of adsorbents in the separation of REEs. Both single and multi-component systems are included to ensure a holistic representation of the field. Additionally, the selected literature must have been published within the last decade to capture the latest advancements and trends. The inclusion criteria serve as a filter, ensuring that the chosen studies align with the project's objectives and contribute meaningfully to the synthesis of information.

**4.3 Comparative Analysis:**

A critical component of the methodology is the adoption of a comparative analysis approach. Selected studies are scrutinized for the adsorbents utilized, the mechanisms involved, and the reported performance metrics. This comparative lens allows for the identification of trends, strengths, and limitations associated with different adsorbents. By systematically comparing the methodologies and outcomes of diverse studies, the project aims to distill key insights that contribute to a nuanced understanding of the state-of-the-art in REE separation.

**4.4 Data Visualization:**

To enhance clarity and facilitate a deeper understanding of the findings, the methodology incorporates data visualization techniques. Figures, diagrams, and plots are employed to illustrate chemical structures of prominent adsorbents, graphically represent separation efficiency and selectivity, and depict adsorption mechanisms. These visual aids not only serve as powerful tools for conveying complex information but also contribute to the synthesis of results in a more accessible format.

**4.5 Iterative Process:**

The methodology is designed as an iterative process, allowing for continual refinement and adjustment based on emerging insights. As new information is synthesized, the methodology enables a dynamic approach to explore additional dimensions, revisit specific areas, or delve deeper into particular aspects that emerge as crucial during the course of the review.

**5. Figures/Diagrams/Plots:**

The incorporation of tables detailing the parameters of various adsorbents used for the separation of rare earth elements (REEs) is instrumental in providing a structured and comparative overview. These tables serve as a quantitative foundation, allowing for the systematic analysis of different adsorbents across key parameters. The tables are seamlessly integrated into the broader literature review, providing a quantitative complement to the qualitative analysis. They act as reference points for discussions on the merits and challenges associated with different adsorbents. Visualizing the data in tabular form enhances the reader's understanding and facilitates a more nuanced interpretation of the findings.

The following table shows the list of parameters for various adsorbents used in the separation of various REEs. The tables serve as a quantitative cornerstone in the exploration of adsorbents for REE separation. Their systematic structure enables a comparative analysis that is integral to the synthesis of information, offering a clear and organized representation of the diverse parameters influencing the performance of different adsorbents in the complex process of rare earth element separation.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Element** | **Adsorbent** | **Type of system** | **Composition** | **pH** | **Time (min)** | **Temp (oC)** | **Reference** |
| Cerium (Ce) | 4-tert-Octyl-4-((phenyl)diazenyl)phenol (TPDP) | single |  | 3.5 | 25 | 25 | [1] |
| bio-inspired urchin-like structured hydroxyapatite (UHdA) | multi | La3+, Ce3+, Sm3+, Ce3+ | 6 |  | 45 | [2] |
| (UHdA@Fe3O4) |
| hydrous ferric oxide | single |  | 6.8 | 75 | 30 | [3] |
| rice husk (RH) | single |  |  | 25 | 25 | [4] |
| 1-Phenyl-3-methyl-4-benzoyl-5-pyrazolone(HPMBP) | single |  | 4 | 1200 | 25 | [5] |
| Crab shell | multi | Ce3+, Eu3+ | 6 | 60 | 25 | [6] |
|
| Activated Charcoal | single |  |  |  | 20 | [7] |
| Transcarpathian clinoptilolite | single |  | 6 |  | 25 | [8] |
| synthetic resin purolite C100 | single |  | solution pH | 1440 | 25 | [9] |
| Hydrated MnO2 | single |  | 5 | 7 | 30 | [10] |
| Lanthanum(La) | Purolite  S950 | single |  | 5 | 60 | 60 | [11] |
| Sargassum polycystum | single |  | 5 |  | 25 | [12] |
| Crab shell | single |  | 5 | 25 | 30 | [13] |
| Neem sawdust | single |  | 6 | 240 | 50 | [14] |
| Tangerine peel | single |  | 5 | 60 | 25 | [15] |
| Stichococcus bacillaris | single |  | 6 | 10 | 25 | [16] |
| AC from RH | single |  | 3.5 | 60 | 25 | [17] |
| GO nanosheets |  |  | 6 | 15 | 25 | [18] |
| MgFe-LDH-Cyanex272 | multi | La3+, Nd3+ | 1 | 120 | 25 | [19] |
|
| CL-Zn/Al LDH nanocomposite | multi | La 3+, Ce 3+, Y 3+ | 7 | 10 | 47 | [20] |
|
|
| Praseodymium (Pr) | free-S. wighti | single |  | 5 | 90 | 32 | [21] |
| free-T. conoides | 240 |
| polysulfone immobilized S. wightii |
| polysulfone immobilized T. conoides |
| crab shell | single |  | 5 | 35 | 50 | [22] |
| orange peel | 50 |
| macroporous strong acid ion exchange resin (D72) | single |  | 3 | 900 | 25 | [23] |
| Terminalia arjuna | single |  | 6.63 | 480 | 28 | [24] |
| magnetite nanoparticles functionalized with phosphonic acid group (PA-MNPs) | single |  | 4 | 5 | 25 | [25] |
| polysulfone immobilized Turbinaria conoides | multi | Pr 3+, Tm 3+ | 5 | 1812 | 32 | [26] |
| 1938 |
| polyethylenimine methylene sodium phosphonate grafted Merrifield resin (PEIPR-Na) | multi | Pr 3+, U 3+, La 3+ | 4.2 | 250 | 35 | [27] |
| 2.9-5.7 | 22 |
| >4.3 | 30 | 27 |
| hydrogenated Dowex 50WX8 resin | multi | Pr 3+ , Dy 3+, Y 3+ | 1 | 15 | 25 | [28] |
|
|
| 2-ethylhexylphosphonicacid-mono-2-ethylhexylester (PC88A) | multi | Pr 3+, Nd 3+ | 2.5 | 420 | 23 | [29] |
| Laminaria digitata algal beads and foams | single |  | 4 | 300-360 | 25 | [30] |
| Neodymium (Nd) | Expanded vermiculite | single |  | 3 | 180 | 10 | [31] |
| (trimethoxy-silyl)propyl diethylphosphonate (DEPPS) | single |  | 6 | 1440 | 25 | [32] |
| magnetic iron oxide (Fe3O4) | single |  | 8.22 | 120 | 35 | [33] |
| 2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester(P507) | single |  | 4 | 1200 | 25 | [34] |
| Gel-type acrylic resin (110 resin) | single |  | 6 | 4320 | 25 | [35] |
| amino phosphonic groups based on chitosan nano magnetite particles | single |  | 4 | 15 | 21 | [36] |
| diethylenetriamine-pentaacetic acid (DTPA) functionalizedmagnetic nanosorbents | single |  | 4 | 30 | 21 | [37] |
| chitosan and iron(III) hydroxide (ChiFer(III)) composite | single |  | 4 | 4320 | 25 | [38] |
| phosphoryl-functionalized algal-PEI beads | single |  | 3.0-4.0 | 30-40 | 21 | [39] |
| Chitosan-Manganese-Ferrite Magnetic Beads | single |  | 4 | 50 | 25 | [40] |
| Samarium (Sm) | PAN@SDS | single |  | 4.8 | 30 | 25 | [41] |
| Activated Charcoal | single |  | 4 | 30 | 60 | [42] |
| DEHPA and TOPO extract | single |  |  | 30 | 25 | [43] |
| Bentonite-N-(2- hydroxyethyl) ethylenediamine | single |  | 4 | 2 | 20 | [44] |
| Microspheres of Haematite | single |  | 7 | 60 | 25 | [45] |
| GO/CS/ZrP/Si nano composite | single |  | 4.5 | 240 | 65 | [46] |
| Multiwalled carbon nanotubes | single |  | 5 | 120 | 30 | [47] |
| Sargassum biomass | single |  | 5 | 60 | 20 | [48] |
| 1-acryloyl-3-phenyl thiourea Hydrogels | single |  | 7 | 720 |  | [49] |
| SBA-15-ZMVP | single |  | 5 | 60 | 55 | [50] |
| Europium (Eu) | multiwalled carbon nanotubes (MWCNTs) | single |  | 6 | 60 | 25 | [51] |
| 5-tert-butyl-2-hydroxybenzaldehyde  thiosemicarbazone (THTB) | single |  | 5 | 180 | 25 | [52] |
| zeolite | single |  | 8 | 1200 | 30 | [53] |
| Sargassum | multi | Eu 3+, La 3+, and Yb3+ | 2 | 60 | 25 | [54] |
| Saccharomyces cerevisiae immobilized in glutaraldehyde cross-linked chitosan | single |  | 5 | 40 | 25 | [55] |
| Fe3+- and Al3+-doped zirconium- and titanium-phosphates | single |  | 3 | 2880 | 25 | [56] |
| Magnetite Nanoparticles | multi | Eu 3+, La 3+ | 7 | 240 | 25 | [57] |
| manganese oxide nanoparticles (Mn3O4 NPs) | multi | Eu 3+, Gd 3+ | 5 | 300 | 25 | [58] |
| H‐APC activated carbon | single |  | 5 | 120 | 20 | [59] |
| Cu-BTC | single |  | 7 | 180 | 25 | [60] |
| Ca-BTC |
| Al- BTC |
| Gadolinium (Gd) | chelating resin | single |  | 5.5 |  | 35 | [61] |
| copolymer of styrene and divinylbenzene resin (TVEX-PHOR) | multi | Gd 3+, Tb 3+ | 5.22 | 120 | 25 | [62] |
| Transcarpathian clinoptilolite | multi | Gd 3+, Nd 3+ | 9.5 |  | 20 | [63] |
| Cyphos@silica | multi | Gd 3+, Nd 3+ | 3.5 | 200 | 25 | [64] |
| Dowex HCR-S/S resin | single |  | 4 | 40 | 25 | [65] |
| Zirconium silico antimonate (ZrSiSb) | multi | Gd 3+, Ce 3+ | 4.12 | 30 | 30 | [66] |
| montmorillonite-supported zero-valent iron nanoparticles (nZVI-M) | single |  | 4.7-5 | 240 | 30 | [67] |
| three-dimensionally interconnected macroporous imprinted chitosan films (3DIM-IFs) | single |  | 7 | 180 | 25 | [68] |
| acid-modified Transcarpathian clinoptilolite | single |  | 9.5 | 1440 | 21 | [69] |
| graphitic carbon nitride (g-C3N4) |  |  | 6 | 40 | 25 | [70] |
| Terbium (Tb) | Transcarpathian clinoptilolite | single |  | 8.25 | 1440 | 20 | [71] |
| cellulosic material extracted from rose stems (CRS) | single |  | 6.5 | 60 | 25 | [72] |
| raw poplar biomass | single |  | 4 | 60 | 25 | [73] |
| poly(pyrimidine-thiophene-amide (PPTA) | multi | Dy 3+, Tb 3+, Nd 3+ | 5.5 | 130 | 25 | [74] |
| Na-modified Transcarpathian clinoptilolite | single |  | 8.8-9.0 | 150 | 25 | [75] |
| f algal/PEI beads (ALPEI) | multi | Tb 3+, La 3+ | 5 | 30 | 21 | [76] |
| PAN/UiO-66-(COOH)2 NFMs | multi | Tb 3+, Eu 3+ | 6 | 360 | 25 | [77] |
| brown algal biomass (alginate) and polyethylenimine (PEI) beads | single |  | 4 | 2880 | 25 | [78] |
| core@shell nanoparticles (NPs) | single |  | 6 | 120 | 25 | [79] |
| inorganic silicon vanadate (SiV) | multi | Tb 3+, Eu 3+ | 5.5 | 200 | 25 | [80] |
| Dysprosium (Dy) | expanded vermiculite | single |  | 5 | 180 | 25 | [81] |
| Phosphorus functionalized nanoporous carbon | multi | Dy 3+, Nd33+ |  | 60 | 25 | [82] |
| Dy3+ ion-imprinted membrane material (II-MAC) | single |  | 7 | 80 | 25 | [83] |
| ion imprinted mesoporous silica materials (IMS) | single |  | 2 | 150 | 25 | [84] |
| amorphous zirconium phosphate (am-ZrP) | single |  | 2.5 | 900 | 25 | [85] |
| polyethylenimine-epoxysilane-silica | single |  | 2.4 | 1440 | 25 | [86] |
| dysprosium ion imprinted polymer (IIP) particles | single |  | 7.2 | 10 | 30 | [87] |
| aluminum-iron-magnesium silicate | single |  | 3.5 | 180 | 25 | [88] |
| HDTMA-Br- and NaOH-treated bark powder of Mangifera indica | single |  |  | 420 | 30 | [89] |
| mesoporous silicas functionalized with phosphonic groups ≡ Si(CH2)2P(O)(OH)2 | single |  | 4.8 | 60 | 20 | [90] |
| Holmium (Ho) | algal biomass/polyethyleneimine beads, ALPEI | multi | Ho 3+, Ce 3+, Sc 3+ | 4 | 40 | 22 | [91] |
| bark powder of Mangifera indica | single |  | 2.5 | 300 | 28 | [92] |
| TVEX–PHOR resin | multi | Ho 3+, Pr 3+ | 3.5 | 30 | 25 | [93] |
| Erbium (Er) | D113-III resin | single |  | 6.04 | 1320 | 25 | [94] |
| nitrilotris(methylene)phosphonic acid (NTMP) | single |  | 5.7 | 240 | 60 | [95] |
| iron oxide (Fe3O4), persimmon tannin (PT), and graphene oxide (GO) as Fe3O4/PT/GO | single |  | 4 | 300 | 30 | [96] |
| chitosan (GLA-Chit) functionalized by poly(aminocarboxymethylation) (PCM-Chit) | single |  | 5 | 300 | 40 | [97] |
| embossed bacterial cellulose aerogel (BCP-I) | single |  | 5 | 300 | 40 | [98] |
| Thulium (Tm) | 3–(((5–ethoxybenzenethiol)imino)methyl)–salicylic acid (EBMS) | single |  | 3.5 | 40 | 25 | [99] |
| Ytterbium (Yb) | gel-type weak acid resin (110) | single |  | 5.5 | 1500 | 25 | [100] |
| SQD−85 resin | single |  | 5.5 | 600 | 35 | [101] |
| Pseudomonas aeruginosa | multi | Yb 3+, La 3+ | 5 | 24 | 22 | [102] |
| sericin/alginate particles crosslinked with poly(vinyl alcohol) (SAPVA) | single |  | 5 | 120 | 25 | [103] |
| Lutetium (Lu) | composite hybrid material (CMHs) | single |  | 4 | 45 | 25 | [104] |
| Transcarpathian clinoptilolite | single |  | 10 | 150 | 21 | [105] |
| Scandium (Sc) | aminocarbonylmethylglycine | single |  | 3 | 480 | 25 | [106] |
| mesoporous silica | single |  | 3 |  | 25 | [107] |
| macro porous TRPO/SiO2-P adsorbent | single |  | 2 | 120 | 25 | [108] |
| resin containing glycol amic acid | single |  | 1 | 1440 | 25 | [109] |
| Yttrium (Y) | titanium dioxide with surface  arsenate groups (4As–TiO2) | single |  | 9 | 40 | 20 | [111] |
| magnesium oxide–calcium alginate hydrogel | single |  | 2 | 90 | 40 | [112] |
| Purolite C100Na Resin | single |  | 1.5 | 1440 | 30 | [113] |
| cobalt iron oxide alginate nanocomposite | single |  | 4.7 | 180 | 25 | [114] |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Element** | **sorption capacity (mg/g)** | **order of model** | **model** | **elluent** | **Reference** |
| Cerium (Ce) | 192.31 |  | Langmuir | 0.2 M HNO3 | [1] |
| 248.39 | pseudo-second order | Weber-Morris model | 0.1M HNO3 | [2] |
| 230.01 |
| 1.4 |  | Freundlich and D–R | double distilled water | [3] |
| 0.101 | pseudo-second order | Langmuir | 0.2 M HNO3 | [4] |
| 106.38 |  | Langmuir |  | [5] |
| 144.9 | pseudo-first order | Sheindorf–Rebhun–Sheintuch equation |  | [6] |
| 49.5 |
|  | pseudo-second order |  |  | [7] |
|  |  | Langmuir |  | [8] |
| 16.71 |  | Langmuir |  | [9] |
| 1.75 |  | Freundlich | 0.01 HCl | [10] |
| Lanthanum(La) | 38.52 | pseudo-second order | Langmuir |  | [11] |
| 69.4 |  | Langmuir |  | [12] |
| 140.1 | pseudo-second order | Langmuir |  | [13] |
| 160.2 | pseudo-second order | Freundlich | 0.1 HCl | [14] |
| 154.86 | pseudo-second order | Langmuir |  | [15] |
| 51.02 | pseudo-second order | Langmuir | 0.1 M HNO3 | [16] |
| 175.4 | pseudo-second order | Langmuir | 0.1 M HNO3 | [17] |
| 85.67 | pseudo-second order | Langmuir | 0.1 M HNO3 | [18] |
| 480.8 |  | Langmuir | 0.01 HCl | [19] |
| 192.3 |
| 92.51 | pseudo-second order | Langmuir | 0.1 M HCl | [20] |
| 96.25 |
| 102.25 |
| Praseodymium (Pr) | 131.4 | pseudo-first order | Sips |  | [21] |
| 146.4 | pseudo-first order | Sips |
| 111.2 | pseudo-first order | Sips |
| 119.5 | pseudo-first order | Sips |
| 57.8 | pseudo-second order | Langmuir | 0.1 M NaOH | [22] |
| 49.9 |
| 294 | pseudo-second order | Langmuir | 1 M HCl-0.5 M NaCl | [23] |
| 1.225 | pseudo-second order | Langmuir | 0.1 M HCl | [24] |
| 20-24 | pseudo-second order | Langmuir and Freundlich | 0.1 M H2SO4 | [25] |
| 1.14 |  | Sheindrof–Rebhun–Sheintuch | 0.01 HCl | [26] |
| 1.23 |
| 6 | pseudo-second order |  | 5M HCl | [27] |
| 19 |
| 1 | 5M H2SO4 |
| 30 |  | Langmuir | 1M citric acid | [28] |
| 50 | Toth | 1M HNO3 |
| 60 | Langmuir | 1M Ammonium carbonate |
| 671.4mg/cm2 | pseudo-second order | Langmuir | 4.5 M H2SO4 | [29] |
| 110-120 | pseudo-second order | Sips | 2 M HCl/0.05 M CaCl2 | [30] |
| Neodymium (Nd) | 69.236 | pseudo-first order | Langmuir | 0.3 M CaCl2 | [31] |
| 160 |  | chemical reaction and film pore | 1M HNO3 | [32] |
| 24.88 | pseudo-second order | Langmuir | 0.05 M HNO3 | [33] |
| 35.18 | pseudo-second order | Langmuir | 1M HCl | [34] |
| 308 | pseudo-first order | Langmuir | 3M HCl | [35] |
| 125.63 | pseudo-first order | Langmuir and Sips | 0.2 M HCl | [36] |
| 11.5 | pseudo-second order |  |  | [37] |
| 30.9 | pseudo-second order | Langmuir | dil HCl | [38] |
| 210.59 | pseudo-first order | Langmuir | 0.2 M HCl/0.5 M CaCl2 solution | [39] |
| 44.29 | pseudo-second order | Langmuir | MeOH, EDTA | [40] |
| Samarium (Sm) | 97.37 | pseudo-second order | Redlich-Peterson and Sips |  | [41] |
|  |  | Langmuir |  | [42] |
|  | pseudo-second order | Freundlich |  | [43] |
| 17.7 |  |  |  | [44] |
| 14.48 | pseudo-second order | Lagregen |  | [45] |
| 135.3 | pseudo-second order |  |  | [46] |
| 89.28 | pseudo-second order | Langmuir |  | [47] |
| 51.1 | pseudo-second order | Langmuir |  | [48] |
| 106.78 | pseudo-second order | Freundlich |  | [49] |
| 41.66 | pseudo-second order | Langmuir |  | [50] |
| Europium (Eu) |  | pseudo-second order |  | HCl | [51] |
| 176.31 |  | Langmuir | 0.2 M HNO3 | [52] |
| 24.39 | pseudo-second order | Langmuir |  | [53] |
| 75.2 | pseudo-second order | Langmuir | 0.2 M HCl | [54] |
| 19.41 | pseudo-second order | Freundlich | 1 M KSCN | [55] |
| 50.5 |  | Langmuir |  | [56] |
| 37.9 | pseudo-second order |  |  | [57] |
| 26.8 | pseudo-second order | Langmuir | 2 M HNO3 | [58] |
| 46.5 | pseudo-second order | Langmuir | 0.5 M HCl | [59] |
| 635 | pseudo-second order | Langmuir and Freundlich | 0.1 M EDTA | [60] |
| 642 |
| 628 |
| Gadolinium (Gd) | 281 | liquid film diffusion | Langmuir | 2 M HCl | [61] |
| 15.49 | pseudo-second order | Freundlich | 0.1 M HCl | [62] |
| 6.5 |  |  | 1 M KCl | [63] |
| 19.81 | pseudo-second order | Langmuir | 1 M HNO3 | [64] |
| 66 | pseudo-second order | Langmuir and Freundlich | 10% NaCl | [65] |
| 27.2 | pseudo-second order | Langmuir | CaCl2 | [66] |
| 301.91 | pseudo-second order | Langmuir and D-R |  | [67] |
| 51.36 | pseudo-second order | Langmuir | 10 % (v/v) HAc | [68] |
| 8.2 |  |  | 1 M HCl and 1 M KCl acidified by a HCl | [69] |
| 25 |  |  |  | [70] |
| Terbium (Tb) | 6.1 |  |  | 7M HNO3/ 1 M NaCl | [71] |
| 16.9 | particle diffusion controlled process | Freundlich | 0.2 M H2SO4 | [72] |
| 9.4 | pseudo-second order | Sips | 0.1 M HNO3 | [73] |
| 25.89 |  | Langmuir | 0.2 M HNO3 | [74] |
| 5.521 |  |  | 7 M HNO3 | [75] |
| 162.103 | pseudo-first order | Langmuir | 0.2 M HCl/0.5 M CaCl2 | [76] |
| 214.1 | pseudo-second order | Langmuir | 0.25 M HCl | [77] |
| 59.279 |  |  | oxalic acid precipitation | [78] |
|  | pseudo-second order | Temkin |  | [79] |
| 34.39 | pseudo-second order | Langmuir and Freundlich | 0.4 M HNO3 | [80] |
| Dysprosium (Dy) | 52 |  |  | CaCl2 | [81] |
| 344.6 | pseudo-first order |  |  | [82] |
| 23.3 | pseudo-second order | Langmuir | 1 M HCl | [83] |
| 22.33 | pseudo-second order | Langmuir | EDTA | [84] |
| 377.54 | pseudo-second order |  | dil HNO3 | [85] |
| 98 |  |  | H2SO4 | [86] |
| 39.19 |  |  | HCl | [87] |
| 13.975 |  | Langmuir | 0.2 M magnesium nitrate hexahydrate | [88] |
| 55.04 | pseudo-second order | Langmuir | 0.1 M HCl | [89] |
|  |  |  | 0.025 EDTA | [90] |
| Holmium (Ho) | 87.41 | pseudo-second order | Sips | 0.2 M HCl/ 0.5 M CaCl2 | [91] |
| 10.4 | pseudo-second order | Langmuir | 0.05 M H2SO4 | [92] |
| 50.4 | pseudo-first order | Freundlich | 0.1 M H2SO4 | [93] |
| Erbium (Er) | 250 | pseudo-first order | Lagergren | 4 M HCl | [94] |
| 106.277 | double exponential | Freundlich | 0.15 M H2SO4 | [95] |
| 366.6 | pseudo-second order | Langmuir |  | [96] |
| 145 | pseudo-second order | Freundlich | 0.5 M acidic thiourea | [97] |
| 95.99 |  | Langmuir |  | [98] |
| Thulium (Tm) | 168.57 |  | Langmuir | 0.25 M HNO3 | [99] |
| Ytterbium (Yb) | 265.8 |  | Langmuir | 3 M HCl | [100] |
| 347.6 | pseudo-second order | Langmuir | 1 M HCl | [101] |
| 397 |  |  | 0.1 M EDTA | [102] |
| 26.3 | pseudo-first order | EMTR | 0.3 M HNO3 | [103] |
| Lutetium (Lu) | 171.76 |  | Langmuir | 0.35 M HNO3 | [104] |
| 9.37 |  |  | 1 M NaCl | [105] |
| Scandium (Sc) | 12.72 |  | Langmuir | 1 M H2SO4 | [106] |
| 1 | pseudo-second order | Langmuir |  | [107] |
| 13.3 |  | Langmuir | 0.1 M H2SO4 | [108] |
| 540 |  |  | 2 M HCl | [109] |
| Yttrium (Y) | 65 | Elovich | Langmuir |  | [111] |
| 5.6 | pseudo-second order | Freundlich and D-R | 1 M H2SO4 | [112] |
| 180 | pseudo-second order | Freundlich |  | [113] |
| 78.22 | pseudo-second order | Freundlich | 1 M HNO3 | [114] |

**6. Results:**

The results section of the internship report constitutes the culmination of the systematic literature review and comparative analysis of various adsorbents employed for the separation of rare earth elements (REEs) from single and multi-component systems. This section is structured to provide a detailed synthesis of findings, emphasizing key trends, notable outcomes, and insights derived from the collected data.

**6.1 Categorization of Adsorbents:**

One of the central outcomes of the analysis is the categorization of adsorbents based on their types and structures. This categorization sheds light on the diversity of materials used in REE separation, encompassing traditional ion-exchange resins, versatile activated carbon, and innovative hybrid materials. The categorization lays the foundation for a nuanced understanding of how different materials perform in various scenarios.

**6.2 Performance Metrics:**

Quantitative data on performance metrics such as selectivity, efficiency, and capacity are systematically presented. This includes a comparative analysis of how different adsorbents perform under varying conditions. The results highlight the strengths and limitations of each material, offering a comprehensive overview of their practical utility in real-world applications.

**6.3 Operational Conditions:**

The results section delves into the operational conditions influencing the adsorption process. Parameters such as pH, temperature, and concentration are explored in relation to their impact on adsorption efficiency. This information is crucial for optimizing separation processes and designing practical applications of adsorbents in industrial settings.

**6.4 Comparative Analysis:**

The heart of the results lies in the comparative analysis of different adsorbents across multiple parameters. The tables listing the parameters of various adsorbents facilitate a side-by-side comparison, allowing for the identification of trends and patterns. Noteworthy findings, such as the superior selectivity of certain adsorbents for specific REEs or the challenges associated with regeneration, are systematically discussed.

**7. Conclusion:**

In summary, the literature review on adsorbents for rare earth element (REE) separation within the context of wastewater treatment illuminates promising pathways for addressing the challenges inherent in this critical field. The discussions underscore the potential of various adsorbents, ranging from traditional ion-exchange resins to innovative hybrid materials, in effectively treating wastewater containing REEs.

By examining mechanisms, comparative performance metrics, and operational conditions, this review contributes to the understanding of how adsorbents can be tailored for efficient REE removal in wastewater. The prospects for future research emphasize the importance of sustainable practices, calling for the exploration of materials that align with environmental considerations.

In the synthesis of key trends, the conclusion provides valuable insights for wastewater treatment practitioners seeking effective, selective, and environmentally conscious methods for REE separation. Challenges and considerations, including scalability and environmental impact, are acknowledged, guiding future endeavors toward more holistic solutions.

In the realm of wastewater treatment, this literature review serves as a roadmap, informing decision-makers and researchers about the advancements, challenges, and potential avenues for sustainable rare earth element separation, contributing to the ongoing dialogue in the pursuit of cleaner and more efficient wastewater treatment practices.

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