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Review

Understanding the factors affecting the adsorption of Lanthanum using different adsorbents: A critical review

Sidra Iftekhar [a, *], Deepika Lakshmi Ramasamy [a], Varsha Srivastava [a], Muhammad Bilal Asif [b], Mika Sillanpää [a, c]

[a] Department of Green Chemistry, School of Engineering Science, Lappeenranta University of Technology, Sammonkatu 12, FI-50130 Mikkeli, Finland
[b] Strategic Water Infrastructure Laboratory, School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong NSW 2522, Australia
[c] Department of Civil and Environmental Engineering, Florida International University, Miami, FL 33174, USA

HIGHLIGHTS

- Highlights of process parameters using conventional batch assays for La.
- Statistical analysis of process parameters for La adsorption by various adsorbents.
- Knowledge of adsorption isotherm, kinetics and thermodynamics and desorption for La.
- Mechanism for hydroxyl, carboxyl, amine and phosphoryl groups was proposed.

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ABSTRACT

Over the past few decades, removal and recovery of Lanthanum (La) have received great attention due to its significance in different industrial processes. In this review, the application of various adsorbents viz. biosorbents, commercial and hybrid materials, nanoparticles, nanocomposites etc. have been summarized in terms of the removal and recovery of La. The influence of various operating parameters including pH, dosage, contact time, temperature, coexisting ions, adsorption kinetics, isotherm and thermodynamics were investigated. Statistical analysis of the obtained data revealed that 60% and 70% of the authors reported an optimum pH of 4–6 and a dose of 1–2 g/L, respectively. It can be concluded on the basis of an extensive literature survey that the adsorbent materials (especially hybrids nanocomposites) containing carboxyl, hydroxyl and amine groups offered efficient La removal over a wide range of pH with higher adsorption capacity as compared to other adsorbents (e.g., biosorbents and magnetic adsorbents). Also, in most cases, equilibrium and kinetics were followed by Langmuir and pseudo second-order model and adsorption was endothermic in nature. To evaluate the adsorption efficiency of several adsorbents towards La, desorption and regeneration of adsorbents should be given due consideration. The main objective of the review is to provide an insight into the important factors that may affect the recovery of La using various adsorbents.

Contents

* Corresponding author.
E-mail addresses: sidra.iftekhar@lut.fi, sidra_iftekhar@yahoo.com (S. Iftekhar).

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1. Introduction

Rare earth elements (REEs) consist of 17 elements with 15 lanthanides and two pseudo lanthanides (Sc and Y) (Vijayaraghavan and Balasubramanian, 2010; Sadovsky et al., 2016; Iftekhar et al., 2017d; c; Jacinto et al., 2018). Based on their atomic number, REEs can be further sub-divided into: (i) light rare earth elements (LREEs) such as La, Ce, Pr, Nd, Pm, Sm, Eu and Gd; and (ii) heavy rare earth elements (HREEs) such as Tb, Dy, Ho, Er, Tm Yb, Lu and Y. The application of REEs, particularly lanthanides, is increasing due to their unique catalytic, magnetic, optical and chemical properties (Tadjarodi et al., 2015; Rahman et al., 2017; Negrea et al., 2018). They are often termed as the “seeds of technology” or “industrial vitamin” due to their extensive use in different fields such as chemical engineering, electronics, metallurgy and medicine (Iftekhar et al., 2017b; Xu et al., 2018). Currently, China, Australia and USA are the leading producers of REEs, with China holding 90–95% of global REE production (Feder and Kramer, 2010; Das and Das, 2013; Anastopoulos et al., 2016; El-Magied et al., 2017). In 2015, the global demand of REEs was 119,650 metric tons per year and is likely to escalate by 5% until 2020 (Zhou et al., 2017). Despite their extensive use, the extent of REE recycling/reuse has been reported to be only 1% in 2011 (Binnemans et al., 2013; Sadovsky et al., 2016; Jacinto et al., 2018). Notably, many countries, which import REEs for manufacturing, have already started looking for an alternative source of these metals, because their availability is prone to become a major concern in near future (Das and Das, 2013; Shaver, 2015). On the other hand, some countries and companies, including Toyota, are trying to secure the mines in Australia, South Africa and Greenland to meet their future demands (Feder and Kramer, 2010; Anastopoulos et al., 2016).

Among REEs, lanthanum (La), a very copious and reactive element has gained special attention due to its unique physico-chemical properties (Das et al., 2014). La is found in the minerals of rare earths such as allanite, monazite, cerite and bastnasite (Awwad et al., 2010). The principle ores consisting of 25% and 38% of La are monazite and bastnasite, respectively. Mischmetals are used in making lighter flints that contains approximately 25% of La (Marwani et al., 2013). Lanthanum is used either in pure form or in combination with other elements for the production of super alloys, catalysts, batteries and ceramics (Tadjarodi et al., 2015; Jacinto et al., 2018). The effluent discharge of these industries (specially from mining activity and ore processing) often contains high concentration of La, which can contaminate the environment and endanger human health being carcinogenic and geno-toxic towards human peripheral blood lymphocytes (Wang et al., 2016b). In addition, due to the accumulation of La in aquatic biota and its toxicity (Chen et al., 2018; Li et al., 2018), scientific community feels the need to develop an effective and economical method for the separation and pre-concentration of La from waste streams. Several methods have been developed for the treatment of La such as membrane separation, ion exchange, chemical precipitation, solvent extraction and adsorption (Ponou et al., 2014; Sadovsky et al., 2016; Zhao et al., 2016a,b; Iftekhar et al., 2017a; Gao et al., 2018). Among these separation methods, adsorption has been reported to be the most efficient, eco-friendly and economical technique for the treatment and recovery of La (Sadovsky et al., 2016). To date, various materials including raw and modified biosorbents (Diniz and Volesky, 2005a; b), nanocomposites (Wu et al., 2013), hybrids (Pal et al., 2012; Zhang et al., 2013), silica-based materials (Tadjarodi et al., 2015), magnetic, inorganic (Rahman et al., 2014) and carbon-based commercial materials (Koochaki-Mohammadpour et al., 2014) have been studied for the recovery of La from the aqueous medium. Excellent reviews on REEs adsorption by different materials have been published in last five years (Das and Das, 2013; Anastopoulos et al., 2016). However, the influence of operating parameters on adsorption along with mechanism of removal has not been comprehensively reviewed. In addition, there is a need to focus on specific REE (e.g., La). Due to its commercial significance, performance of a wide range of adsorbents for the removal of La should be critically analyzed. To date, no other review is available, discussing the removal of La by different adsorbents as a function of various operating parameters.

Therefore, the review mainly consists of four aspects. The main goal of this review is to provide highlights of process parameters that can affect La adsorption. In addition, adsorption isotherm, kinetics and thermodynamics are critically discussed. The third section of the article outline adsorption mechanism of La. Finally, dynamic adsorption of La is reviewed and discussed.

2. Statistical trend of adsorbents

The statistical trends based on the Scopus database of numerous adsorbents studied extensively in the previous years for removal/recovery of REEs and La are illustrated in Fig. 1. This implies that more research is being conducted for the removal/recovery of REEs after 2010, more than half of which is for La. Additionally, a continual increment in the application of nanocomposites and