Adsorption of rare earth metals from water using a kenaf cellulose-based poly(hydroxamic acid) ligand

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Abstract

A kenaf cellulose-based poly(hydroxamic acid) ligand was synthesized from poly(methylacrylate) grafted cellulose and applied towards the adsorption of rare earth metals from aqueous media. The starting materials and final product were examined by FT-IR, FE-SEM, and ICP-MS. Remarkable maximum adsorption results were obtained for the earth metals La3+, Ce3+, Pr3+, Gd3+, Nd3+, Eu3+, and Sm3+, with values of 260, 245, 235, 220, 210, 195, and 192 mg g−1, respectively. The adsorption capacities of the ligand for adsorption of rare earth metals were well fitted with the pseudo-second-order rate equation. Further, the adsorption properties of the rare earth ions were nicely matched with the Langmuir isotherm model, (R2 > 0.99), thus suggesting that the adsorbent surface of the ligand is monolayer and homogenous in nature. The reusability of the created ligand was evaluated by carrying out sequential sorption/desorption experiments, indicating that the developed adsorbent can be reused for at least 10 cycles without incurring any significant losses to its primary removal capabilities.

1. Introduction

Lanthanide elements, commonly referred to as rare earth elements (REEs), comprise a group of metallic chemical elements consisted of a similar chemical and physical nature [1]. REEs are utilized in diverse industrial processes, such as in the production of superconductors, glass-pigments, additives, catalysts, medicines, and cosmetics [2]. Owing to their metallurgical, chemical, magnetic, electrical, catalytic, and optical properties, REEs are also extensively incorporated in the manufacturing of super-magnets, information storage systems, lighter flints, fluorescent lamps, batteries, lasers, and high technology electronics [3,4]. However, unlike other heavy and precious metals, with the exception of few locations in China, REEs are not easily found in ore deposits in concentrations that allow for easy extraction [5]. Owing to their increasing demand, the separation and recovery of worthwhile REEs metals from diluted aqueous streams is being undertaken alongside primary mining industry applications [6,7].

Various methods, such as solvent extraction [8], co-precipitation [9], and ion-exchange [10], have been utilized for pre-concentration and recovery of REEs; however, existing methods today are burdened by various limitations, such as secondary pollution and high operational costs [11]. Among different extraction methods, the adsorption of REEs on solid surfaces by coordination can be said to be one of the most acceptable methods available today, as the adsorption system is mostly non-toxic, and consists of a simple operation and the straightforward development of adsorbents [7,11]. Extensive studies regarding development and employment of such adsorbents have been reported for cellulose [11], chitosan [7], activated carbon [12], β-cyclodextrin [13], aminocarboxylic sorbents [14], β-cyclodextrin (β-CD) [15], silica [16], and titanium dioxide [17]. Of note, an EDTA-modified chitosan-based adsorbent was prepared and used for recovery of rare earth ions from water [7]. In other work, Michel et al. reported on the development of an EDTA-linked β-CD dimer showing good chemical sensing and strong complexes with Lanthanide ions [18].

Yong et al. [19] reported on the development of hydrogel adsorbents consisted of a monolithic open-cellular framework for enrichment of rare-earth metals. The obtained results showed rapid adsorption kinetics with equilibrium obtained at 30 min, with higher adsorption capacities of 384.62 and 333.33 mg g−1 for La and Ce, respectively. Sun et al. [20] described the synthesis of an adsorbent containing carbon nano-shells obtained from polydopamine, which has since been applied for adsorption of REEs in various high-tech industries [20]. To meet industry demands, various industrial processes being developed for pre-concentration and separation of REEs today include the use of techniques such as solvent extraction [21,22], ion exchange [23], adsorption [24], liquid membranes [25], and MILs [26,27]. A practical adsorbent must be characterized by high selectivity for low concentration rare earth ions, absorbability at lower pH levels, rapid adsorption/desorption rates, high adsorption capacity, reusability, and a low cost of production. Among various methods...