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Original Article

Removal of Strontium Ions by Immobilized *Saccharomyces Cerevisiae* in Magnetic Chitosan Microspheres

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ABSTRACT

A novel biosorbent, immobilized *Saccharomyces cerevisiae* in magnetic chitosan microspheres was prepared, characterized, and used for the removal of Sr^{2+} from aqueous solution. The structure and morphology of immobilized *S. cerevisiae* before and after Sr^{2+}adsorption were observed using scanning electron microscopy with energy dispersive X-ray spectroscopy. The experimental results showed that the Langmuir and Freundlich isotherm models could be used to describe the Sr^{2+} adsorption onto immobilized *S. cerevisiae* microspheres. The maximal adsorption capacity (q_m) was calculated to be 81.96 mg/g by the Langmuir model. Immobilized *S. cerevisiae* was an effective adsorbent for the Sr^{2+} removal from aqueous solution.

1. Introduction

Radiotoxic ion such as Sr-90 is one of the most hazardous metal ions in radioactive waste because of its high solubility, high transferability, easy accumulation in organisms, and long half-life [1,2]. Conventional methods for the removal of radiotoxic ions from aqueous solution include thermal treatment, chemical precipitation, membrane separation, solvent extraction, and ion exchange [3,4]. Adsorption is a physicochemical process that is economical and highly effective for removing radiotoxic ions from aqueous solution [5]. Different adsorbents have been examined for radiotoxic ions removal, such as bentonite [6], tobermorite [7], bone char [8], and Egyptian soils [9]. However, they possess low adsorption capacities in their natural forms and need to be modified to improve their adsorption characteristics.

The natural polymers and their derivatives can be utilized as economic and environmental-friendly materials for the removal of heavy metals and radionuclides from aqueous solution with high efficiency [5,10–12]. Chitosan is a suitable

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biopolymer for the removal of radiotoxic ions from aqueous solution since the $-NH_2$ and $-OH$ groups on chitosan can act as chelating groups [5,13]. The major application of chitosan and its derivatives is based on its ability to bind heavy metal ions. In addition, chitosan has many chemical and biological properties, such as biocompatible, bioactive, and biodegradable properties. It has been used in many biomedical and industrial applications [5,14].

To improve the adsorption capacity and to prevent the dissolution of chitosan in acidic medium, mechanical properties and various modified chitosan have been studied, respectively, for heavy metal removal [13,15–17].

Microbial immobilization using chitosan may also improve the adsorption capacity. Due to the liquid/solid separation problem, free yeast cells appear to be unsuitable for practical application [11]. Immobilization techniques have been used for the removal of heavy metal ions in recent years [18,19]. Chitosan is a suitable support material for microbial immobilization because of its characteristics, such as resistance to chemical degradation, improvement of mechanical strength, and antibacterial property. Microorganisms immobilized by polymers have many advantages, including easy separation from the reaction medium, continuous or repeated use, and enhancement in the stability of microorganism [19]. The advantages of magnetic chitosan for immobilization of *Saccharomyces cerevisiae* include that the magnetic performance will make the biosorbents easy to separate under the magnetic field; thus, after biosorption, the biosorbents can be easily separated, regenerated, and reused. Moreover, the addition of magnetic particles Fe_3O_4 will also enhance the mechanical strength of the biosorbents, which is very important for prolonging the lifetime of the biosorbents in a practical application.

Different kinds of microorganisms were used for the adsorption of Sr^{2+}, including *S. cerevisiae* [20–22], *Bacillus subtilis* [23,24], and *Pseudomonas mendocina* [25]. We used the waste biomass of *S. cerevisiae* produced from a local brewery for the adsorption of Pb^{2+}, Ag^{+}, Cs^{+}, and Sr^{2+} from aqueous solution [20]. Naeem et al. [21] examined the adsorption of protons, Cd^{2+}, Pb^{2+}, Sr^{2+}, and Zn^{2+} onto the fungal species *S. cerevisiae*. They measured the electrophoretic mobility of the cells as a function of pH and modeled the acid/base properties of the fungal cell wall by invoking a nonelectrostatic surface complexation model. The affinity of the fungal cells for the metal ions follows the following trend: $Pb^{2+} > Zn^{2+} > Cd^{2+} > Sr^{2+}$. Their results suggested that *S. cerevisiae* may be a novel biosorbent for the removal of heavy metal cations from aqueous waste streams. Peng et al. [22] prepared the immobilized *S. cerevisiae* on the surface of chitosan-coated magnetic nanoparticles and applied for removing Cu(II) from aqueous solution. They examined the effect of the initial pH, initial Cu(II) concentration, and contact time on the adsorption of Cu(II). Cu(II) adsorption followed the Langmuir model, and the maximal adsorption capacity was 144.9 mg/g. Fein et al. [23,24] conducted the metal adsorption experiments onto *B. subtilis* and determined the bacterial surface stability constants for Cd^{2+}, Cu^{2+}, Pb^{2+}, Al^{3+}, Co^{2+}, Nd^{2+}, Ni^{2+}, Sr^{2+}, and Zn^{2+}. Borrok and Fein [25] studied the effect of ionic strength on the adsorption of Cd(II), Pb(II), and Sr(II) onto the surfaces of *P. mendocina*.

The objective of this work was to prepare a novel biosorbent, i.e., immobilized *S. cerevisiae* by magnetic chitosan microspheres and use it for removing Sr^{2+} from aqueous solution.

2. Materials and methods

2.1. Chemicals and reagents

Chitosan with 90% deacetylation degree was provided by Sinopharm Chemical Reagent Co., Ltd. (SCRC; Beijing, China). All other chemicals used in this study were analytical grade and supplied by Beijing Chemical Plant. Fe(III) and Fe(II) used in this study were $FeSO_4 \cdot 7H_2O$ and $FeCl_3 \cdot 6H_2O$, respectively. $SrCl_2 \cdot 6H_2O$ was used to prepare the stock solution of 1,000 mg/L.

2.2. Preparation of immobilized *S. cerevisiae*

S. cerevisiae biomass was collected from a local brewery and immobilized using the following procedure: (1) chitosan (2 g) was completely dissolved in 100 mL of 2 wt% acetic acid in deionized water; (2) sodium alginate (1 g) was added and dissolved completely, and 20 g of *S. cerevisiae* were added; (3) the mixture was stirred for 30 minutes; and (4) Fe(III) and Fe(II) (0.02 mol:0.01 mol) were dissolved in the above solution, stirred for 30 minutes, and added into 300 mL of 10% (w/v) NaOH solution (containing 7.5 mL of ethyl acetate) drop-wise using a syringe to form magnetic chitosan beads.

2.3. Characterization of the immobilized *S. cerevisiae* microspheres

Scanning electron microscopy (SEM-EDX) was measured using FEI Quanta 200 FEG SEM instrument of FEI Company. SEM-EDX Q2 Q3 was used to explore the properties of the immobilized *S. cerevisiae* microspheres.

2.4. Adsorption experiments

The radioactive wastewater produced in nuclear power plants at normal operation is usually relatively clean, which means that there are a few impurities with the exception of radionuclides. Therefore, no other cations were added for the adsorption experiments in this study.

For batch adsorption experiments, 15 mL of Sr^{2+} solution was mixed with 30 mg of adsorbents in 20-mL glass bottles. The pH values were adjusted using 0.1M HCl or 0.1M NaOH. For the adsorption isotherm experiments, the initial Sr^{2+} concentration varied from 5 mg/L to 300 mg/L at 30°C. After equilibration, the samples were taken and used for the determination of Sr^{2+} concentration.

2.5. Analytical methods

The concentration of Sr^{2+} was analyzed using atomic adsorption spectroscopy (AAS6 Vario, Analytik Jena AG, Jena, Germany). The equilibrium adsorption capacity was calculated using the following equation: Q4

$$q_e = (C_0 - C_e)V/W, \quad (1)$$

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