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Two-stage biosorption of selenium from aqueous solution using dried biomass of the baker's yeast *Saccharomyces cerevisiae*

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ABSTRACT

In the present study, the biosorption of selenium ion onto dried biomass of baker's yeast, *Saccharomyces cerevisiae*, in an aqueous system was investigated. An optimization of selenium biosorption was performed by varying the pH, the initial ion concentration and the biomass dosage. Selenium sorption isotherms were obtained at optimal conditions and the sorption equilibrium data fitted to the Sips isotherm model. The maximum uptake capacity by the Sips model was about 39.0 mg g^{-1}. The mass balance equations permitted a theoretical determination of the selenium concentration and the amount of biosorbent needed for achieving the required heavy metal removal. It was observed that two adsorption stages and 2 g of baker's yeast biomass biosorbent were required to remove 96.10% of 50 mg L^{-1} selenium from 100 ml aqueous solution. In this condition, the percentage removal of selenium in stage one was 88.10% and stage two was 67.20%. The thermodynamic study revealed that the biosorption process of selenium has an endothermic and spontaneous nature and is promoted by increasing the temperature from 298 to 318 K. The results also showed that the pseudo-second-order kinetic model correlated well with the experimental data, with an activation energy of 40.67 kJ mol^{-1}. Based on the results of the percentage removal in the two-stage biosorption system, it could be concluded that the dried biomass of *S. cerevisiae* is a suitable sorbent for the removal of selenium ions from aqueous solution.

Introduction

Discharge of industrial wastewaters containing hazardous materials and heavy metals into the environment can be harmful to humans, animals, plants and to urban ecosystems [1,2]. Therefore, preventing the release of these substances into the ecosystem is desirable, because the presence of any of these substances in excessive quantity will often interfere with beneficial usage of water due to their toxicity and biomagnification effects on ecology [3]. The development of methods with economic advantages over technologies for industrial waste purification was considered as one of the most important environmental concerns [4,5]. There are various treatment methods that can be employed to remove heavy metals from contaminated wastewater, including chemical precipitation, evaporation, coagulation/flocculation, solidification/stabilization, solvent extraction, extraction with chelating agents, ion exchange, membrane operation, electrochemical operation, cementation, vitrification and adsorption [6,7].

In this context, the biosorption by employing cost effective biomaterials promises to be an excellent alternative to using inorganic sorbents, providing cost effective, eco-friendly and relatively less complex means for the removal of selenium from water [8,9]. Biosorption is an attractive technology using inactive and dead biomass to remove heavy metals from aqueous solutions, in the absence of metabolic activity necessary for intracellular accumulation [10,11]. On the other hand, biosorption represents the sum of all passive interactions of the cell wall with metal ions. These include adsorption, ion exchange and surface complexation reactions with functional groups at the cell surface. Binding sites for metal ions localized on the surface of the cell structure include lipid groups of carboxyl, hydroxyl, and phosphate, proteins and polysaccharides [12]. *Saccharomyces cerevisiae* is widely used in food and beverage industries, while it is also a kind of solid waste. In comparison with other microorganisms used for metal removal, although *S. cerevisiae* is a mediocre biosorbent, it is still considerably good biomaterial for biosorption studies because of its unique characteristics [13]. Göksungur [14] has reported using waste baker's yeast biomass treated with ethanol for adsorption of cadmium and lead ions from aqueous solution, while *Bingol* et al. [15] employed cationic surfactant-modified yeast for adsorption of

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chromium anions and Lin et al. [16] used *S. cerevisiae* waste biomass for the adsorption gold (Au^{3+}). These researches suggest the potential of baker's yeast for the removal also of other heavy metals from aqueous solution in the future. Furthermore, Vieira and Volesky [17], Kapoor and Viraraghavan [18] and Jianlong and Can [13] have shown that the questioned yeast has potential application as biosorbent in the field of biosorption. At first *S. cerevisiae* (baker's yeast) is easy to cultivate at large scale. It can also be grown with unsophisticated fermentation techniques and inexpensive growth media. Second, the biomass of *S. cerevisiae* can be obtained from various food and beverage industries. Third, *S. cerevisiae* is not usually a waste, but a commercial commodity and considered safe. Therefore, biosorbent made from *S. cerevisiae* may be easily accepted by the public when applied in practice as it can be used at large scale with low cost, especially for treating of large amount of wastewater containing heavy metal in low concentration [19].

Selenium (Se) is a trace element that is essential for biological systems at doses below 40 $\mu g\, g^{-1}$, but like all essential element, it is toxic at dose above 4000 $\mu g\, g^{-1}$. Se also plays an important antioxidant and anti-carcinogenic role and it neutralizes heavy metals toxicity [20]. Normal human dietary intake of selenium is about 50–200 $\mu g\, d^{-1}$ and Se toxicity may manifest itself already at dietary levels of 400 $\mu g\, d^{-1}$. Selenium is introduced into the environment from different sources, both natural and anthropogenic [21]. The main sources of selenium are oil refineries, mining of phosphates and sewage sludge. However, the problem of selenium results from reactions in a combination of specific minerals and their precipitation rates such as occur in seleniferous, alkaline soils in arid and semiarid regions. Selenate (SeO_4^{2-}), selenite (SeO_3^{2-}), elemental selenium, and selenide are the four species of selenium that exist in soil, whereas Se(IV) and Se(VI) are dominant in aqueous systems. In general, selenium species in the +4 oxidation state are more toxic than the species containing selenium in the +6 state [22]. After it was generally recognized that selenium at low concentrations in drinking water causes severe health effects, the technologies for selenium removal have become increasingly important. Furthermore, there has been a remarkable increase of interest in studying selenium because of the strong correlation between cancer and selenium concentration in the diet [23,24]. A variety of treatment technologies have been reported for biosorptive of selenium in contaminated waters. Examples include ion exchange, reverse osmosis, nanofiltration, solar ponds, chemical reduction with iron, microalgal and bacterial treatments, alumina adsorption, Fe^{3+} coagulation/filtration, lime softening, bagasse fly ash, granular activated carbon (GAC) and powdered activated carbon (PAC) and ferrihydrite adsorption [25–28]. Although these approaches can remove selenium to below 5 ppb under optimal conditions, most of the systems have technical and/or economical constraints.

In our previous study we have demonstrated the feasibility of reusing biomass of *S. cerevisiae* to remove heavy metal ions from aqueous solutions and found it to be suitable for regenerating three times in successive adsorption–desorption cycles, with no significant impact on the adsorption capacity [3]. In the literature, to the best knowledge of this author, no selenium biosorption from aqueous solution has been carried out by a dried biomass of *S. cerevisiae*. The objective of the present study is to optimize biosorption of selenium (VI) ions in aqueous solution onto pretreated dried biomass of baker's yeast, *S. cerevisiae*, in a batch experiment. For a better understanding of different stages of biosorption at varying selenium concentrations, pH levels and sorbent dosages, the two-stage batch adsorption was used to maximize the selenium uptake. Furthermore, this mode of study provided an applicable process design for optimizing the baker's yeast dosage by using the mathematical and equilibrium data in the two-stage batch adsorption process.

Materials and methods

Microorganism and growth condition

Baker's yeast *S. cerevisiae* (PTCC5010) was provided from Research and Technology Department of Ministry of Sciences (Persian Type Culture Collection) in the form of freeze-dried, and then cultured in sterilized medium. The composition of growth medium was (grams per liter): glucose, 15; $(NH_4)_2SO_4$, 9; $MgSO_4$, 2.5; yeast extract, 1; KH_2PO_4, 1; K_2HPO_4, 0.2. The medium was sterilized by autoclaving at a pressure of 1.5 atm and temperature of 121 °C for 20 min. While the temperature and pH of the growth medium was at ambient temperature and 4.5, respectively, without shaking. The yeast cells were grown for 48 h (at end of exponential phase) and then deposited in order to separate the liquid and solid phase.

Preparation of biomass for biosorption

The yeast biomass was deactivated by autoclaving at a pressure of 1 atm and temperature of 121 °C for 20 min, then it was dried in a freeze dryer for 24 h. The dried biomass was ground and screened through a sieve with 100 mesh. The pretreatment of the biosorbent was carried out with non-living yeast cells in 700 g L^{-1} ethanol solution for 20 min at room temperature. Then, it was centrifuged at 3600 rpm for 10 min and the ethanol solution was discarded. The ethanol washed biomass was rinsed several times with distilled water to remove excess ethanol and adsorbed nutrient ions. The rinsed yeast was again centrifuged and the remaining biomass was dried in a freeze dryer for 24 h [14]. The dried cells were ground and screened as mentioned above. The purpose of grinding dried yeast was to make a homogenized yeast biomass in order to destroy biomass aggregates and increase uptake capacity [29].

Surface structure of biosorbent

The ground biomass was stocked in the refrigerator for use in biosorption studies. Scanning electron microscope (SEM, Phillips XL30, Holland) was used for observing *S. cerevisiae* after treatment by 70% ethanol. Pore-volume, pore size and BET (Brunauer Emmett Teller) surface area of untreated and ethanol pretreated biomass of *S. cerevisiae* were measured to confirm the generation of pore during the pretreatment. The textual characteristic was determined by BET and BJH (Barrett–Joyner–Halenda) surface area analyzer (Quantachrome instruments, Nova 2.2). Before measurement, the dried biomass samples were degassed under vacuum for 14 h at 80 °C, and the specific surface area and porosity was then measured by nitrogen adsorption–desorption method at 77.3 K. The specific surface areas were analyzed by single point BET method at $p/p_o = 0.354$. The pore volume was measured at the single point of $p/p_o = 0.986$. Average pore size diameter were also obtained from desorption isotherms by the BJH method.

Biosorption experiments

The selenium solutions of desired concentration were prepared by diluting the stock solutions with distilled water. The chemical used for this study was of analytical grade of selenium dioxide (SeO_2) supplied by Merck (Germany). A stock selenium solution of 1000 mg L^{-1} was prepared by dissolving 1.4339 g of selenium dioxide in a 10% HCl (v/v) and diluted up to mark in a 1000 ml of distilled water.