Biosorption of zinc and copper ions by immobilized yeast under aerobic and anaerobic conditions

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Abstract. Studies have been conducted to evaluate the efficiency of biosorption of zinc and copper ions by brewing yeast *Saccharomyces cerevisiae* immobilized on alginates. The studies were carried out under aerobic and anaerobic conditions using calcium, calcium, magnesium, and aluminum alginates. Under aerobic conditions, when live yeast was immobilized in calcium alginate, the concentration of zinc ions in an aqueous solution decreased within 2 hours by 99.76%, and copper ions by 91.7%. Biosorbents based on a mixture of calcium and magnesium alginates work less effectively (reducing the concentration of zinc ions by 99.3%, and copper ions by 75.8%). Under anaerobic conditions, a biosorbent based on calcium alginate decreased its efficiency in the presence of zinc ions by 0.8%, and that based on aluminum alginate - by 5.4%. In the presence of copper ions, the biosorption efficiency under anaerobic conditions decreased by 2.1%–9.9%, depending on the alginate. This work demonstrates the potential of the brewing yeast *Saccharomyces cerevisiae* as a calcium alginate-based biosorbent.

1 Introduction

Environmental pollution by heavy metals remains one of the most serious environmental problems. Heavy metals are constantly entering aquatic ecosystems, soil and atmosphere as a result of the activities of various industries and agriculture [1, 2, 3].

In recent years, various technologies for the extraction of heavy metals from aquatic environments have been widely studied. These include chemical precipitation, ion exchange, adsorption, membrane filtration, coagulation-flocculation, flotation and electrochemical methods [2, 4]. However, most of them become ineffective at heavy metal concentrations less than 100 mg/l. In addition, various reagents are used for desorption, which leads to the formation of toxic precipitates and secondary environmental pollution [5]. Therefore, the actual practical problem is to develop innovative and cost-effective solutions to clean up the contaminated environment and protect the functioning of ecosystems.

A promising solution to this problem is biosorption using biomaterials such as fungi, bacteria, algae and yeast. This technology is considered to be cost-effective for the

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treatment of wastewater containing heavy metals in the range of 1 to 100 mg/l. Among the promising biosorbents for heavy metal removal, Saccharomyces cerevisiae yeasts are attracting increasing attention. They are widely used in food and beverage production, easily cultivated using cheap media [6, 7, 8]. Yeast cells are produced in large quantities as a by-product in fermentation industries and can be used as a biosorbent [6, 9].

Biosorption is based on the ability of living or nonliving biomass to rapidly adsorb and concentrate heavy metal ions from aqueous solutions. It is based on physicochemical interaction and a cascade of chemical processes in living cells leading to the sorption of xenobiotics. The use of yeast Saccharomyces cerevisiae as the main component of biosorbents for the extraction of heavy metals is interesting because their cells have a large surface area [10, 11].

Structural fragments of yeast cell surface have chelating properties with respect to heavy metal ions due to the presence of ligand-forming functional groups. In this case, living cells after some time (from 15 minutes to 3 hours), from the moment of exposure, are able to express certain proteins (metallothioneins) and peptides (glutathione), realizing the detoxification cascade. A number of authors suggest using activated sludge as sorbents for complex pretreatment of wastewater from heavy metals [12, 13, 14].

Other researchers use sorbents based on chitosan-glucan complex obtained by processing Aspergillus niger [15, 16, 17]. It should be noted that chitin and chitosan-glucan complex are obtained from insect shells and shells of crustaceans (shrimp, etc.), as well as yeast Saccharomyces cerevisiae [18, 19]. Chitin and chitin-glucan complex are a source for the synthesis of the chelating polymer chitosan [15, 20].

Particularly interesting is the use of native forms of yeast fixed on various carriers. Immobilization allows to retain biomass in the reactor, reduces separation costs, increases the mechanical stability of biomass, and increases the sorption area. At the same time, yeast shows the ability to adapt to different environmental conditions such as pH, temperature, high levels of inorganic and organic contaminants [21].

Another aspect to consider in the application of biosorption for the removal of metals is that biosorption serves not only to eliminate these elements but also enables their extraction, thus increasing the interest in this procedure. It is one of the exciting properties of biomass that biomass can be easily modified to adjust it to industrial or commercial applications [22].

However, two negative problems associated with the utilization and recovery of spent biological material are present. One of them occurs when yeast treats a substrate containing heavy metals. This can lead to aggregation and sedimentation of yeast, which reduces the sorption surface area. The second problem is related to the separation of spent sorbent from the substrate and the need to use additional equipment, separators and filters. Technologically, this problem is solved by immobilization of yeast cells on the carrier material [23, 24, 25].

All the above mentioned indicates a great interest in the application of biosorption methods to solve the problems of environmental pollution. Therefore, the search and evaluation of new biosorbents is an urgent task. New biosorbents should be more efficient and economical.

2 Materials and methods

Live yeasts *Saccharomyces cerevisiae* immobilized in calcium, calcium-magnesium and aluminum alginates were used as the main element of the biosorption process. Sorbents based on yeast fixed on alginates had a spherical shape with a diameter of 4-6 mm.

The objects of the study were aqueous solutions of copper and zinc ions in concentrations of 100.0 mmol/l; 10.0 mmol/l; 1.0 mmol/l. Biosorption of metals from the solutions was carried out for 2 hours under aerobic and anaerobic conditions at 23±2°C and pH 5-6. Weakly acidic pH values are the most favorable for increasing biosorption, because at these pH values biomass has a greater number of positive charges, which allows to attract metal ions.

The content of copper and zinc ions in aqueous solutions was determined by potentiometric method. Statistical processing of the obtained results was carried out using the licensed software package Microsoft Excel.

3 Results and discussion

Biosorption under aerobic conditions by live yeast *Saccharomyces cerevisiae* immobilized in calcium alginate and aluminum alginate is the most effective. The concentration of zinc ions in aqueous solution (100 mmol/l) decreases within 2 hours to 0.24 mmol/l, i.e. 12 times, and the concentration of copper ions - 9.1 times (Figure 1). Similar results were obtained at lower concentrations of zinc and copper ions in solution (10 mmol/L and 1 mmol/L).

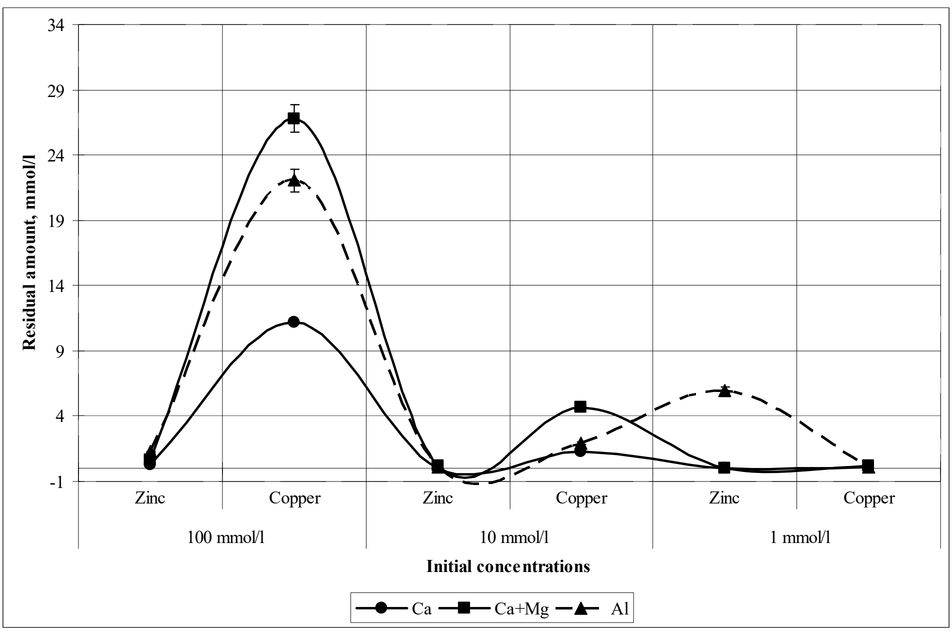

Fig. 1. Residual amount of metal ions after biosorption under aerobic conditions by live yeast Saccharomyces cerevisiae immobilized in different alginates.

Under anaerobic conditions, the sorption properties of Saccharomyces cerevisiae live yeast decreased at all three concentrations. The best sorption properties under these conditions were observed in yeast immobilized on calcium alginate (Figure 2).

Under aerobic conditions, biosorption by live yeast Saccharomyces cerevisiae immobilized in calcium alginate reduced the concentration of zinc ions in aqueous solution within 2 hours by 99.76% and copper ions by 91.7%. The biosorbent based on a mixture of calcium and magnesium alginates was less effective (reducing the concentration of zinc ions by 99.3% and copper ions by 75.8%) (Figure 3).

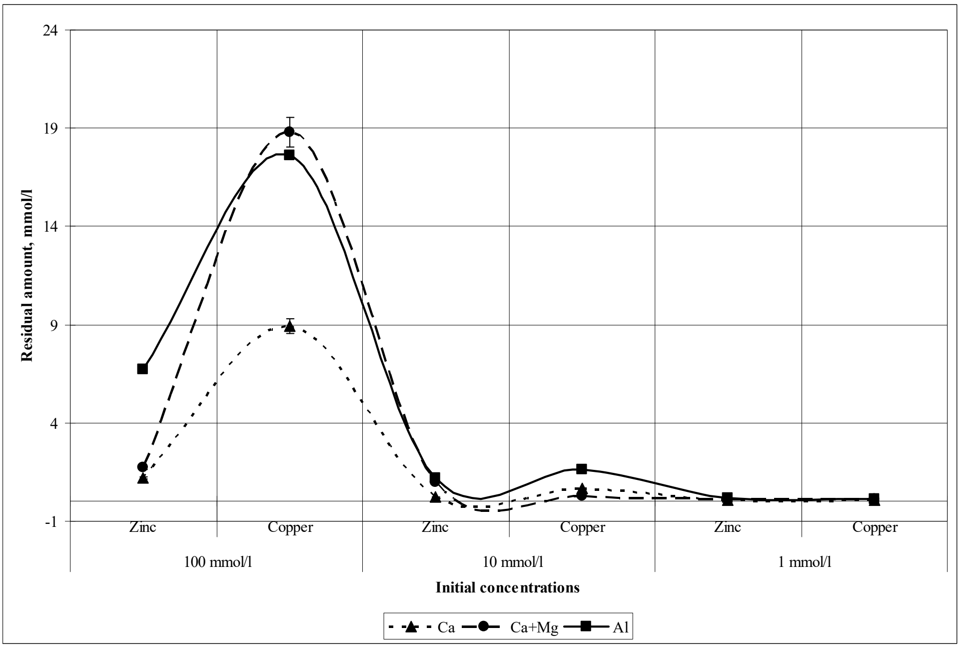

Fig. 2. Residual amount of metal ions after biosorption under anaerobic conditions by live yeast Saccharomyces cerevisiae immobilized in different alginates.

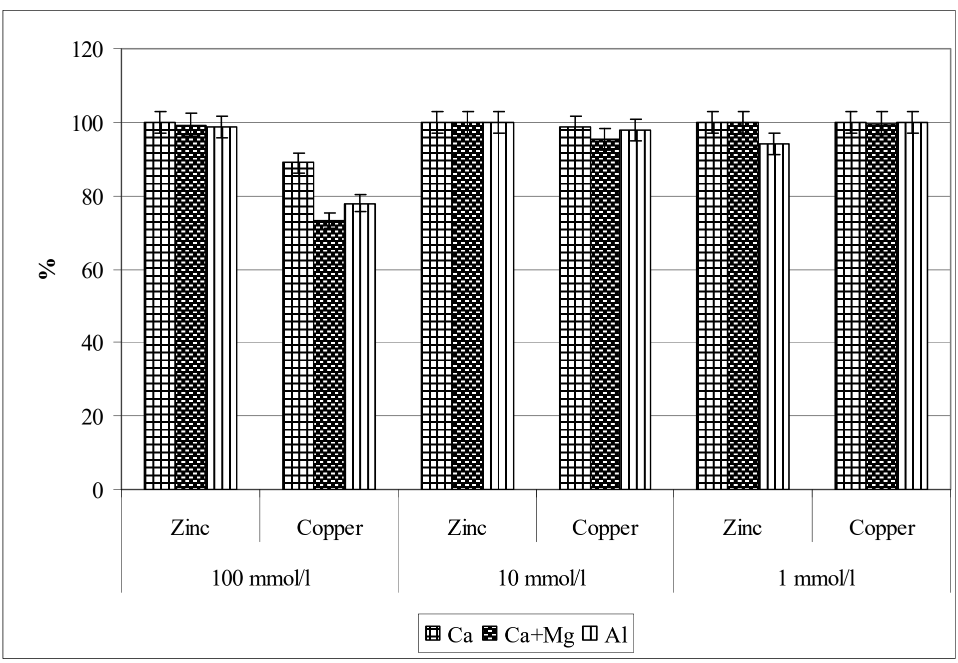

Fig. 3. Sorption efficiency of zinc and copper ions under aerobic conditions.

Under anaerobic conditions, the efficiency of the biosorption process decreased at all three concentrations (Figure 4).

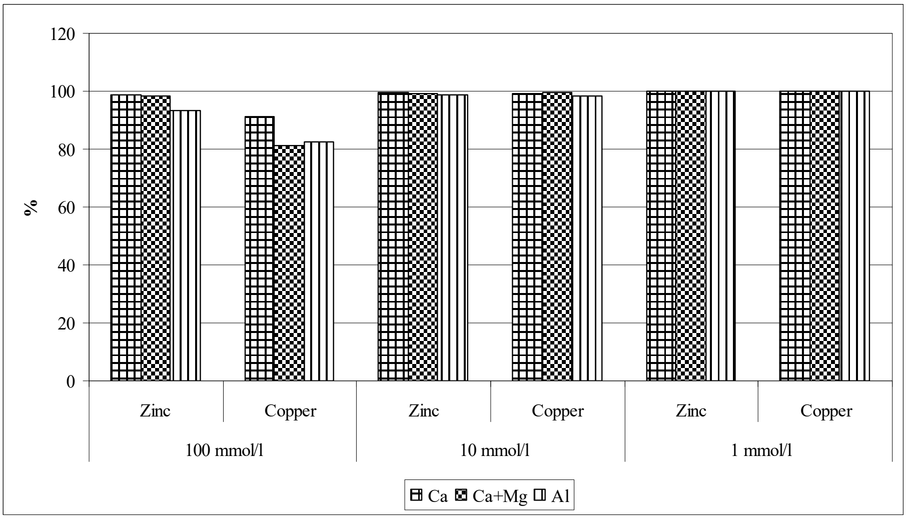

Fig. 4. Sorption efficiency of zinc and copper ions under anaerobic conditions.

Calcium alginate based biosorbent decreased its efficiency in the presence of zinc ions by 0.8% and aluminum alginate based biosorbent decreased its efficiency by 5.4%. In the presence of copper ions, the biosorption efficiency under anaerobic conditions decreased by 2.1%-9.9% depending on the alginate.

4 Conclusion

The use of immobilized sorbents based on live yeast is an effective method of water purification from heavy metal ions.

The best sorption properties of *Saccharomyces cerevisiae* yeast immobilized on calcium alginate show in aerobic conditions.

Under anaerobic conditions, the sorption properties of immobilized *Saccharomyces cerevisiae* yeast decrease. This will further allow to regulate the biosorption conditions to improve the efficiency of sorbents based on live immobilized yeast cells.

The least effective absorption of zinc and copper ions from aqueous solutions under aerobic and anaerobic conditions is observed in biosorbents based on a mixture of calcium and magnesium alginates.

The obtained results can be used for further studies aimed at purification of food liquids from heavy metal ions (juices, mineral and drinking water, etc.).

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