Cadmium(II) Removal from Aqueous Solutions by Biosorption onto Inactive Instant Dry Baker's Yeast

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This study was focused on Cd(II) removal from aqueous solutions by biosorption on inactive instant dry baker's yeast biomass (Saccharomyces cerevisiae). To this end, the influence of pH, biosorbent dosage, contact time and initial metal concentration on Cd(II) removal efficiency and adsorption capacity by the inactive instant dry baker's yeast biomass was investigated. The maximum removal efficiency (98.5 %) and adsorption capacity (49.2 mg/g) were obtained after 30 min contact time, at pH 5.5, for a biosorbent dosage of 0.5 g and an initial metal concentration of 250 mg/L.

Keywords: Cd(II) removal, biosorption, inactive instant dry baker's yeast

Due to the progressive industrialization increasing amounts of heavy metals are being released into the environment causing serious hazards. Furthermore, because of their high mobility, heavy metals ions are being concentrated and accumulated throughout the food chain and ecosystems [1,2]. It was reported that cadmium has a half life of 10 - 30 years in the human body [1]. The toxicity of heavy metals is highly dependent on the speciation of the metal ion in question (i.e. dissolved forms are more toxic than particulate forms) [3]. Some toxic heavy metals ions are very toxic even at low concentration levels (0.001-0.1 mg/L), cadmium is such a case [4]. The worldwide annual production of cadmium is around 20.000 tons [2]. Cadmium is being widely used in a variety of industrial processes, such as: electroplating, paint pigments, alloy preparation, plastics, nickel-cadmium batteries, silver-cadmium batteries, coating operations, smelter operations, photography, television phosphors, etc [2,5]. Therefore, cadmium discharge in natural waters and groundwater is mainly caused by these branches of the industry. Chronic cadmium exposure can cause serious damage to the kidneys, liver and bones, and it is probably best known for its association with "Itai-Itai" disease, specific in Japan [2,6,7]. The admissible levels of cadmium in domestic wastewater, industrial effluents and drinking water according to the European, American and Romanian regulations are listed in table 1.

Unfortunately, classical methods like chemical precipitation, ion exchange, solvent extraction, electrochemical treatment, membrane technologies, reverse osmosis, filtration, evaporation, etc. used for heavy metals decontamination from aqueous systems are ineffective and have several drawbacks, i.e.: incomplete metal removal, high operating costs, high reagent and/or energy requirements, generation of metal-bearing sludge (extremely difficult to be disposed) and are also ineffective at low metal concentrations (< 100 mg/L) [1,4,8-15].

Biosorption is considered a cost-effective, easy to operate alternative technology that can be used for the decontamination of heavy metals containing effluents [1,4,7-11]. Biosorption relies on the general property of living and/or non-living biomass to rapidly bind/ adsorb and concentrate heavy metal ions even from very diluted aqueous solution by physicochemical pathways [8,12,15-16].

Among the many classes of biomaterials (bacteria, fungi, yeast, algae, food industry/agricultural waste, plants, animal origin by-products, etc.) mentioned in the field of biosorption for their heavy metals removal ability, *S. cerevisiae* has received increasing attention from scientists during the past decades due to its unique characteristics [1,4,7,12,15-26]. It is well known that *S. cerevisiae* under diverse forms (lab cultivated yeasts, waste from food industry, immobilized yeast, magnetically/ chemically/ thermally modified yeast, commercial baker's and brewer's yeasts subsequently lab cultivated, fresh/ compressed baker's yeast, etc.). can remove toxic metals (i.e. Pb, Zn, Cd, Hg) and radionuclides (i.e. U, Ce, Cs, Sr), but can also recover precious metals (i.e. Pd, Pt, Au, Ag) and light metals (i.e. Al) from aqueous solutions [1,4,6,9-14,16-28].

Heavy metals biosorption of is a complex process, which is affected by the adsorbent, the type and concentration of heavy metals as well as by other environmental factors [29].

Table 1
ADMISSIBLE LEVELS OF CADMIUM IN DOMESTIC WASTEWATER, INDUSTRIAL EFFLUENTS AND DRINKING WATER ACCORDING TO THE EUROPEAN, AMERICAN AND ROMANIAN REGULATIONS (mg/L) [8-10]

Water type	Regulations		
	European	American	Romanian
Domestic wastewater	0.001-0.004*	0.001-0.004	0.001-0.004
Industrial effluents	0.1-0.2	1	0.2
Drinking water	0.005	0.005	0.005

*Admissible concentration in mg/L.

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This study was focused on Cd(II) removal from aqueous solutions by biosorption onto inactive instant dry baker's yeast. In order to determine the optimum operating parameters and to evaluate the adsorption ability of the inactive instant dry baker's yeast biomass for Cd(II) ions, batch biosorption experiments were carried out at laboratory scale. The influence of *p*H, biosorbent dosage, contact time, and initial metal concentration on Cd(II) removal efficiency and adsorption capacity by the inactive instant dry baker's yeast biomass was investigated.

Experimental part

Biosorbent preparation

Commercial instant dry baker's yeast (*S. cerevisiae*) purchased from local commercial company, was prepared as inactive biomass by oven drying at 105°C for 24 h [30]. Subsequently, the inactive instant dry baker's yeast biomass was stored in desiccators till further use.

Reagents

Cadmium stock solution of 1000 mg/L was prepared by dissolving 3CdSO4·8H2O (Merck, Germany) of analytical reagent grade into distilled water. Cadmium test solutions of different concentrations (10, 25, 50, 100, 150, 200 and 250 mg/L) were obtained by diluting the stock solution. The *p*H of the solutions was adjusted with 0.1 M H_2SO_4 and/or 0.1M NaOH solutions. All reagents were of analytical reagent grade.

Biosorption experiments

The biosorption studies were performed under batch conditions with continuous stirring (200 rpm), at room temperature (20°C), *p*H 5.5 by adding a constant dose of inactive instant dry baker's yeast biomass of 0.5g/100 mL sample of different initial metal concentrations. for 30 min contact time. The *p*H values were measured with an Orion 290 A pH-meter. The batch biosorption experiments were conducted by using an Heildorph Vibramax 100 shaker. The metal loaded biomass was separated from the metal solutions by decantation and Cd(II) equilibrium concentrations in liquid phase were determined by atomic absorption spectrophotometry (Unicam Pay SP9).

Experiments to evaluate the influence of *p*H on Cd(II) biosorption were conducted in the *p*H range of 3.5–6.5 for samples of different initial metal concentrations. In order to investigate the influence of the biosorbent dosage on Cd(II) biosorption, different amounts of biomass in the range of 0.25–2 g/100 mL metal solution were tested for samples of various initial metal concentrations. Experiments to evaluate the influence of contact time on Cd(II) biosorption were carried out in the range of 30-1440 min for samples of different initial metal concentrations. Experiments to investigate the influence of initial metal concentration on Cd(II) biosorption were conducted in the range of 10–250 mg/L.

The removal efficiency and equilibrium adsorption capacity were calculated by means of the following equations [21]:

$$Y = \left(\frac{C_0 - C_e}{C_0}\right) \times 100 \quad (1)$$

$$Q_e = \frac{(C_0 - C_e) \times V}{m} \quad (2)$$

where *Y* is removal efficiency (%); Q_e is the equilibrium adsorption capacity (mg/g); C_0 and C_e are the initial and final/equilibrium metal concentration in solution (mg/L), respectively; *V* is the volume of the metal solution (L) and *m* represents the weight of the dry biosorbent (g).

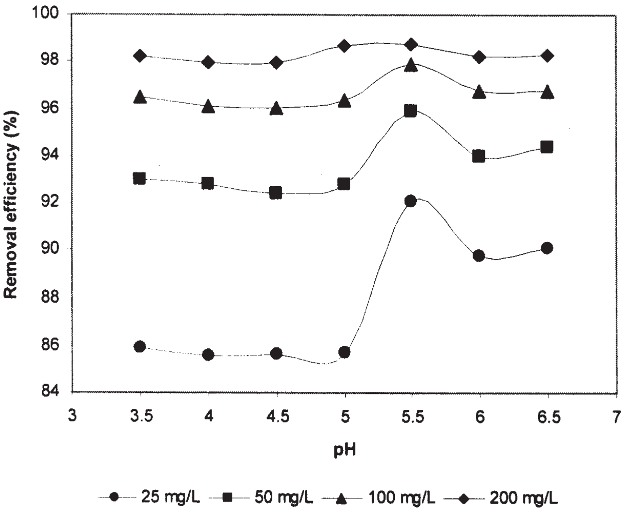

Fig. 1. Influence of *p*H on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass at different initial metal concentrations (biosorbent dosage: 0.5 g, agitation rate: 200 rpm, contact time: 30 min., temperature: 20°C)

Results and discussions

Influence of pH

One of the most important factors affecting heavy metals biosorption is the *p*H of the solution, since it affects the chemical characteristics of the biosorbent, the metal ions speciation and consequently influences the competition between the hydrogen ions and the metal ions for the binding sites present on the biosorbent surface [11, 29, 31]. The influence of *p*H on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass is represented in figure 1.

The experiments concerning the influence of *p*H on Cd(II) biosorption by the inactive instant dry baker's yeast biomass were carried out in the range of *p*H that was not influenced by the metal precipitation. It was reported that the suitable *p*H range for cadmium biosorption is 1-7, because within this range the only stable existing species are represented by hydrated cadmium ions, $[Cd(H_2O)_4]^{2+}$ [32-35]. At higher *p*H values cadmium ions start to precipitate resulting hydroxides ($CdOH^+$ at *p*H 8, $Cd(OH)_2$ at *p*H 9-10, $Cd(OH)_3^-$ at *p*H 11 and $Cd(OH)_4^{2-}$ at *p*H 12) and the precipitation is complete around *p*H 12 [33-35]. From figure 1 it can be noticed that there was an increase in Cd(II) biosorption with increasing *p*H from 3.5 to 5.5 and slightly decreased by increasing the *p*H value to 6.5. This trend was similar for all initial concentrations. The decrease of the removal efficiency at *p*H higher than 5.5 could be assigned to the possible complexation of Cd(II) ions by OH^- groups which prevents metal adsorption [36]. As seen in figure 1, the maximum removal efficiency of Cd(II) by the inactive instant dry baker's yeast biomass was observed at *p*H 5.5. Therefore, it was concluded that the optimal *p*H for Cd(II) removal by the inactive instant dry baker's yeast biomass was 5.5.

Influence of biosorbent dosage

The number of binding sites (functional groups) and exchanging ions available for heavy metal biosorption depends on the amount of biosorbent in the process [37]. According to Hard and Soft Acids and Basis Principle (HSAB) developed by Pearson, hard metal ions (Class A) form stable ionic complexes with hard bases/ligands (F>O>N=Cl>Br>I>S), while soft metal ions (Class B) have a opposite preference towards soft bases/ligands (S>I>Br>Cl=N>O>F) and form covalent complexes [38]. Therefore according to HSAB classification [38], Cd(II)

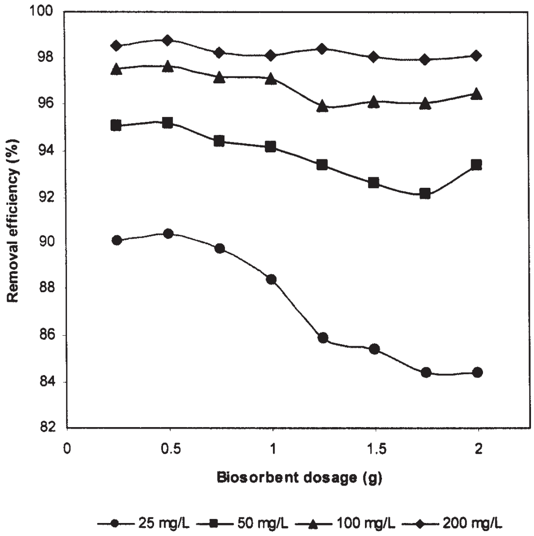

Fig. 2. Influence of biosorbent dosage on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass at different initial metal concentrations (*p*H: 5.5, agitation rate: 200 rpm, contact time: 30 min., temperature: 20°C)

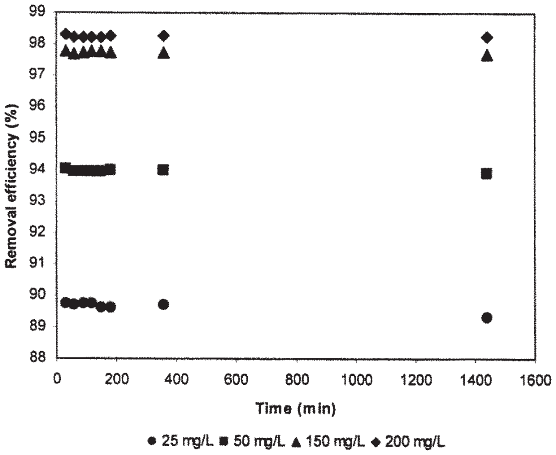

Fig. 3. Influence of contact time on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass at different initial metal concentrations (*p*H: 5.5, biosorbent dosage: 0.5 g, agitation rate: 200 rpm, temperature: 20°C)

is a Class B metal. The influence of the biosorbent dosage on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass is illustrated in figure 2.

As shown in figure 2, by increasing the biosorbent dosage from 0.25 to 0.5 g, Cd(II) removal efficiency increased for all initial metal concentrations. It can be observed that further increase in the biosorbent dosage produces a decrease of the removal efficiency. This trend could be attributed to: the potential interactions between the fuctional groups (carboxyl, amino, hydroxyl, carbonyl, phosphoryl, sulfhydryl, etc) present on the biosorbet cell walls, that inhibits Cd(II) biosorption and once the equilibrium is attained the extra biosorbent probably remains unutilized [20,39]. From figure 2 it can be observed that the optimum biosorbent dosage corresponding to the maximum removal of Cd(II) was 0.5 g.

Influence of contact time

The contact time is a significant factor to be considered for an effective use of a biomass for practical applications [31]. Figure 3 shows the influence of the contact time on Cd(II) removal efficiency by the inactive instant dry baker's yeast biomass.

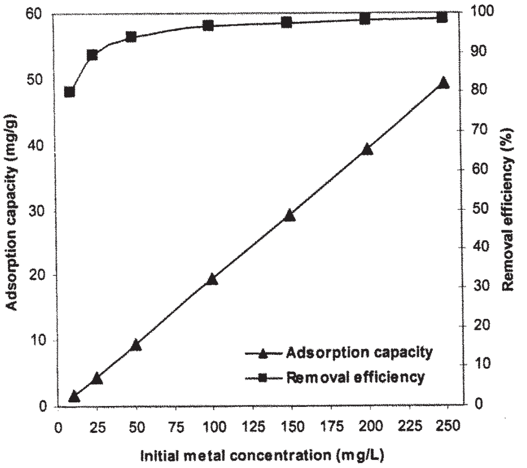

Fig. 4. Influence of initial metal concentration on Cd(II) adsorption capacity and removal efficiency by the inactive instant dry baker's yeast biomass (*p*H: 5.5, biosorbent dosage: 0.5 g, agitation rate: 200 rpm, contact time: 30 min., temperature: 20°C).

As seen from figure 3, Cd(II) biosorption by the inactive instant dry baker's yeast biomass reached equilibrium after 30 min contact time. The removal efficiency increased rapidly and reached maximum after only 30 min due to the availability of binding sites present on the inactive dry baker's yeast biomass surface, and with the progressive saturation of the biosorbent with increasing contact time the biosorption process became less efficient [31,35]. It can be noticed the trend was similar for all initial concentrations. Therefore, considering the aforementioned observations, 30 min was selected as optimum contact time for Cd(II) biosorption by the inactive instant dry baker's yeast biomass.

Influence of initial metal concentration

The initial metal concentration is another important factor that significantly influences the biosorption process. The influence of initial metal concentration on Cd(II) adsorption capacity and removal efficiency by the inactive instant dry baker's yeast biomass is summarized in figure 4.

From figure 4 it can be observed that Cd(II) adsorption capacity increased with increasing initial metal concentration from 1.6 mg/g for an initial metal concentration of 10 mg/L to 49.2 mg/g for an initial metal concentration of 250 mg/L, respectively. Figure 4 also shows that the removal efficiency of Cd(II) by the inactive instant dry baker's yeast biomass followed a similar trend and increased proportionally with the increase in initial metal concentration from 80.1 % (10 mg/L) to 98.5 % (250 mg/L), respectively. The obtained results suggested that the inactive instant dry baker's yeast biomass selected as biosorbent was effective for all concentrations.

A comparison between the adsorption capacities of the inactive instant dry baker's yeast biomass and some previously investigated low-cost adsorbents for Cd(II) ions is given in table 2. From table 2 it can be noticed that the inactive instant dry baker's yeast biomass presents a relatively good adsorption capacity for Cd(II) ions (49.2 mg/g). By further comparing the results obtained in this study with those reported in the literature (table 2) in terms of equilibrium time, we could estimate that Cd(II) biosorption by the inactive instant dry baker's yeast is an effective rapid process.

Table 2
ADSORPTION CAPACITIES OF THE INACTIVE INSTANT DRY BAKER'S YEAST BIOMASS AND SOME PREVIOUSLY INVESTIGATED LOW-COST ADSORBENTS FOR Cd(II) IONS

Adsorbent	pH	Time (min)	Q_e (mg/g)	Ref.
Aeromonas caviae	-	-	155.3	[13]
Oedogonium sp.	5	55	88.2	[36]
Fresh/compressed baker's yeast	6	1440	42.9	[20]
EDTAD-functionalized *S. cerevisiae*	6	-	40.72	[40]
Streptomyces sp. K33	6	1440	38.49	[32]
Pleurotus platypus	6	60	34.96	[35]
Agaricus bisporus	6	240	29.67	[35]
Streptomyces sp. HL-12	6	1440	24.24	[32]
Ethanol treated waste baker's yeast biomass	6	180	15.63	[41]
Enteromorpha compressa macroalgae	6	180	9.5	[42]
S. cerevisiae (PTCC 5010)	5	240	8.56	[43]
Non-living lichen *Ramalina fraxinea* biomass	6	240	7	[44]
Activated sludge biomass	3.5	120	2	[45]
Suspended brewery waste biomass	5.5	40	0.5841	[10]
Immobilized brewery waste biomass	5.5	40	0.5531	[10]
Inactive instant dry baker's yeast biomass	5.5	30	49.2	This study

Conclusions

In this study, the biosorption performance of the inactive instant dry baker's yeast biomass (*S. cerevisiae*) for Cd(II) ions removal from aqueous solution was investigated.

The obtained results indicated that the biosorption performances were strongly affected by the operating factors (*p*H, biosorbent dosage, contact time and initial metal concentration).

The maximum removal efficiency (98.5 %) and adsorption capacity (49.2 mg/g) were reached after 30 min contact time, at *p*H 5.5, for a biosorbent dosage of 0.5 g and an initial metal concentration of 250 mg/L.

The present investigation suggested that biosorption onto inactive instant dry baker's yeast biomass can be used as an effective treatment method for Cd(II) removal from aqueous solutions.

Further investigations will be conducted in order to diminuate Cd(II) concentration after biosorption to the limits imposed by the laws through consecutive biosorption cycles and/or through a biosorption-flotation process.

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