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Uranium removal from acidic aqueous solutions by *Saccharomyces cerevisiae*, *Debaryomyces hansenii*, *Kluyveromyces marxianus* and *Candida colliculosa*

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The sorption of uranium from acidic aqueous solutions (pH 4.5, C_{init} = 10 to 1000 mg U/L) by *Saccharomyces cerevisiae*, *Debaryomyces hansenii*, *Kluyveromyces marxianus* and *Candida colliculosa* was investigated using a batch technique. The U-sorption onto *Saccharomyces cerevisiae* and *Debaryomyces hansenii* followed a Langmuir, while that onto *Kluyveromyces marxianus* and *Candida colliculosa* a Freundlich isotherm. The results demonstrated that all investigated biomasses could effectively remove uranium from acidic aqueous solutions. From all sorbents, *Saccharomyces cerevisiae* appeared to be the most effective with a maximum sorption capacity of 127.7 mg U/g dry biomass.

Introduction

The presence of uranium in the environment is not only due to natural sources but also to various human activities, among them the nuclear power production.[1] Uranium species are both toxic and radiotoxic for humans and for this reason their removal from water and wastewater streams using natural and synthetic sorbents is a subject of continuously increasing importance.[2–5] Microorganisms may also present potential alternatives to the already existing technologies of uranium removal.

The passive sequestration of heavy metals by non-metabolizing non-living biomass is characterized as "biosorption", which is differentiated from "bio-accumulation". Bioaccumulation is the active, metabolically mediated transport and deposition of chemical species on living cells. Although both living and non-living forms of biomass exhibit relatively high affinities to heavy metals, the use of dead biomass for metal sequestration and immobilization offers certain advantages over the living cells.[6] The biomasses are expected to remain relatively intact during the bio-technological processes.[6,7]

In this work the sorption of uranium by *Saccharomyces cerevisiae* from acidic aqueous solutions of pH 4.5 and initial U-concentration 10 to 1000 mg U/L was investigated using a batch technique. *Saccharomyces cerevisiae* is perhaps the most important yeast owing to its use since ancient times in baking and brewing. For comparison purposes uranium sorption experiments were also performed using three other microorganisms common in food industry, *Debaryomyces hansenii*, *Kluyveromyces marxianus* and *Candida colliculosa*. *Debaryomyces (Torulaspora) hansenii* is a cryotolerant, marine yeast. Its cryo- and osmotolerance account for its important role in several agro-food processes. *Kluyveromyces marxianus* is used commercially to produce the lactase enzyme. *Candida colliculosa* is a top fermenting yeast used in the beverage industry (e.g., weizenbier production).

Experimental

Saccharomyces cerevisiae (common commercial yeast) and biomasses *Debaryomyces hansenii, Kluyveromyces marxianus* and *Candida colliculosa* (supplied by *Chr. Hansen A/S* under the code names LAF3, LAF4 and LAF7, respectively) were used for the sorption experiments.

Saccharomyces cerevisiae was cultured at 30 °C for 24 hours in a pre-sterilized (20 min at 121 °C under 1.1 atm pressure) nutrient medium consisting of 120 g/L glucose (D(+)-glucose 1-hydrate, Panreac), 4 g/L yeast extract (Panreac), 1 g/L $(NH_4)_2SO_4$ (Riedel-de Haën), 5 g/L $MgSO_4$ ($MgSO_4 \cdot 6H_2O$, Riedel-de Haën, analytical grade) and 1 g/L KH_2PO_4 (Riedel-de Haën, analytical grade). LAF3, LAF4 and LAF7 were cultured under forced aeration (air filtered through a 0.45 μm filter) for 48 hours. The cultures were sterilized (20 min at 121 °C under 1.1 atm pressure) harvested by centrifugation and washed thoroughly with sterilized distilled water for complete removal of the nutrient. After this procedure the cells were lyophilized and used in the biosorption experiments.

The surface charge of the biosorbents over a wide pH range was determined by ζ-potential measurements using a microelectrophoretic ζ-potential analyzer (Laser Zee Meter 501).

For the sorption experiments uranium solutions of initial concentration between 10 and 1000 mg/L were prepared from a stock solution of $UO_2(NO_3)_2 \cdot 6H_2O$ (Merck pro analysi) in distilled water. The pH of the solutions was adjusted to 4.5 using HCl and NaOH solutions. 50 mg of the biosorbent were shaken in polypropylene tube for 48 hours in a rotary shaker with 10 mL of uranium solution of the appropriate concentration at room temperature. Preliminary

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experiments showed that 48 hours were sufficient to reach equilibrium. After centrifugation, the equilibrium pH was measured and the uranium concentration was determined spectrophotometrically with Arsenazo III at 660 nm.

Results and discussion

ζ-potential measurements indicated that the surface of all biosorbents used was negatively charged for pH higher than 3.5 favoring adsorption of cationic species.

The experimentally determined isotherms for the sorption of uranium by the four investigated sorbents are given in Fig. 1.

In the same figure are also given the curves obtained by fitting the experimental data by the Langmuir isotherm equation:

$$Q_{eq}=\frac{Q_{\max}KC_{eq}}{1+KC_{eq}}$$

where Q_{eq} is the uranium sorbed per unit mass of the sorbent at equilibrium (mg/g), $Q_{\max}$ is the maximum sorption capacity of the sorbent (mg/g), C_{eq} is the uranium equilibrium concentration in solution (mg/L) and K is a constant, or, in the case of the *Kluyveromyces marxianus* and *Candida colliculosa*, the Freundlich isotherm equation is:

$$\frac{x}{m}=K\,C_{eq}^{1/n}$$

where x/m is the uranium sorbed per unit mass of the sorbent at equilibrium (mg/g), and C_{eq} is the equilibrium concentration of uranium in solution (mg/L), K and $1/n$ are constants.

The calculated values (solid lines) were in good agreement with the experimental data. The uranium sorption onto *Saccharomyces cerevisiae* and *Debaryomyces hansenii* could be better described by a Langmuir isotherm whereas the corresponding sorption data on *Kluyveromyces marxianus* and *Candida colliculosa* by a Freundlich isotherm. The maximum sorption capacity, $Q_{\max}$, the K values, the $1/n$ values and the correlation coefficients of the curves obtained by fitting the experimental data by the Langmuir and Freundlich isotherms are given in Table 1.

In the case of *Saccharomyces cerevisiae*, the pH of the solutions at equilibrium was slightly higher than the initial one indicating a possible competitive adsorption of H^+-ions. In contrast, in the cases of *Debayromyces hansenii*, *Kluyveromyces marxianus* and *Candida colliculosa*, the equilibrium pH of the solutions was slightly lower than the initial one.

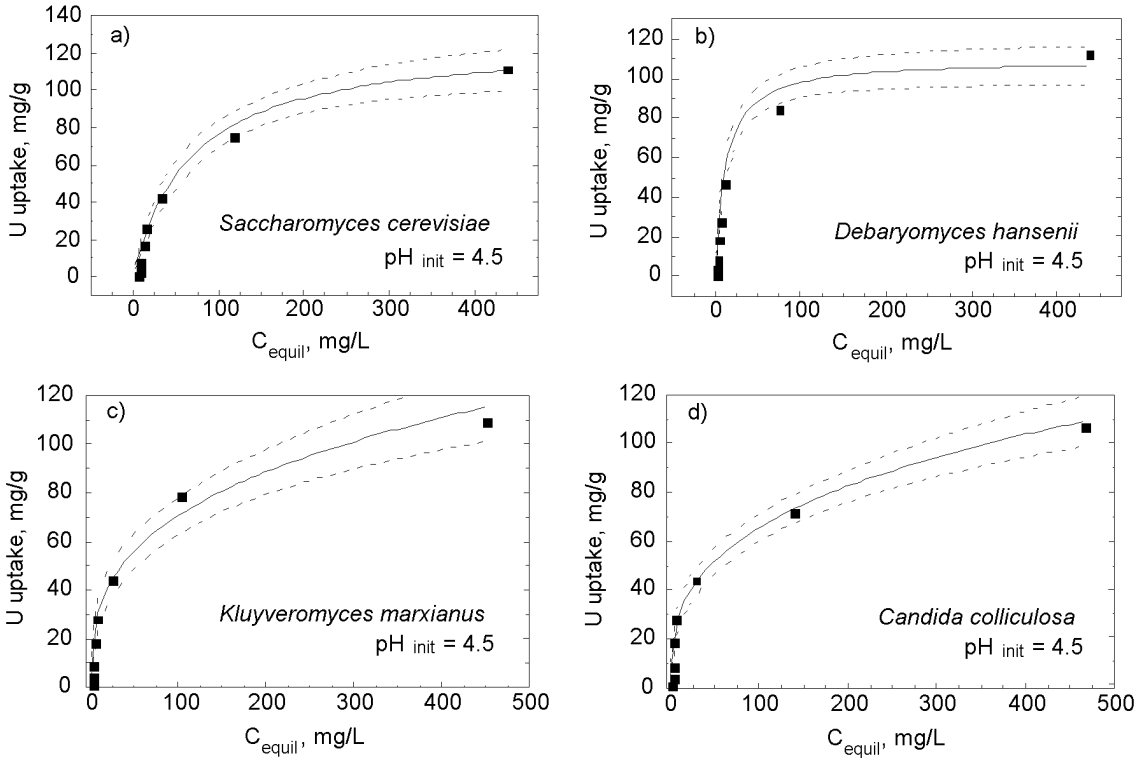

Fig. 1. Adsorption isotherms of U onto *Saccharomyces cerevisiae* (a), *Debaryomyces hansenii* (b), *Kluyveromyces marxianus* (c) and *Candida colliculosa* (d) with Langmuir isotherm fit for (a) and (b) and Freundlich isotherm fit for (c) and (d). The dashed lines represent the 95% confidence limits of the fits. The uptake is given in mg U/g of dry lyophilized biomass

Table 1. Langmuir and Freundlich isotherm fit values and correlation coefficients for the adsorption of U onto four biomasses

Biomass	Q_{max}, mg/g	K	$1/n$	R^2
Saccharomyces cerevisiae	127.7	0.015	–	0.987
Debayromyces hansenii	109.5	0.085	–	0.988
Kluyveromyces marxianus	–	15.8	0.325	0.978
Candida colliculosa	–	14.3	0.331	0.987

The solution pH significantly influences the ionic speciation and consequently the sorption of uranium. In solutions of low pH, the uranyl-ion is the predominant form, whereas at higher pH hydrolysis takes place and uranium hydroxy-complexes represent a significant percentage of the overall species.[6] According to the information in the literature,[8–13] pH 4.5, also used in this work, seems to be optimal for uranium biosorption from aqueous solutions. The dominant species of uranium present in solutions of pH 4.5 are UO_2^{2+} and $(UO_2)_2(OH)_2^{2+}$.[6]

The uptake capacity of the investigated biomasses was higher than the one obtained during the investigation of a number of microorganisms in the literature.[8–10] Several other biomasses showed similar[10,15] and a few higher uptake capacities than the biomasses under investigation in this work. Examples of biomasses with higher uptake capacity are the *Sargassum fluitans* (560 mg/g),[13] *Rhizopus arrhizus* (240 mg/g)[14] and the *Trametes versicolor* (272 mg/g).[15] However, the obtained data did not allow the elucidation of the uranium binding mechanism to the biosorbents used. It is likely that the overall uptake is the result of more than one processes taking place at the biomass/liquid interface. The uptake capacity of the investigated biomasses was higher than the one observed in the case of clay minerals and natural zeolites in raw or homoionic form.[3,16–17]

Conclusions

All investigated biosorbents showed considerable ability to remove uranium from aqueous solutions of initial pH 4.5. The highest sorption capacity was observed for *Saccharomyces cerevisiae* (127.7 mg/g). The sorption onto *Saccharomyces cerevisiae* and *Debaryomyces hansenii* could be described by a Langmuir isotherm, whereas this onto *Kluyveromyces marxianus* and *Candida colliculosa* by a Freundlich isotherm. This might also be indicative of differences in uranium binding mechanisms.

Taking into account the low cost and the easy accessibility of the studied biomasses as well as their relatively high sorption capacity, Q_{max}, obtained during this work, they could be considered as potential sorbents for the removal of uranium from aqueous media.

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References

1. M. EISENBUD, Environmental Radioactivity from Natural, Industrial and Military Sources, Academic Press, San Diego, 1987.
2. D. K. CRAIG, Chemical and Radiological Toxicity of Uranium and its Compounds, Westinghouse Savannah River Company, Report WSRC-TR-2001-00331, 2001.
3. P. MISAELIDES, A. GODELITSAS, Interaction of actinides with natural microporous materials, in: Natural Microporous Materials in Environmental Technology, P. MISAELIDES, F. MACASEK, T. J. PINNAVAIA, C. COLELLA (Eds), NATO Science Series, Kluwer, Dordrecht, 1999, Series E: Applied Sciences, Vol. 362, p. 193.
4. P. MISAELIDES, G. GALLIOS, S. SARRI, D. ZAMBOULIS, E. PAVLIDOU, N. KANTIRANIS, I. ANOUSIS, I. ZHURAVLEV, V. V. STRELKO, Separ. Sci. Technol., 41 (2006) 97.
5. C. C. FULLER, J. R. BARGAR, J. A. DAVIS, M. J. PIANA, Environ. Sci. Technol., 36 (2002) 158.
6. B. VOLESKY, Sorption and Biosorption, BV Sorbex, Inc., Montreal – St. Lambert, Quebec, Canada, 2003.
7. M. BUSTARD, A. P. MCHALE, Bioproc. Eng., 17 (1997) 127.
8. PENG-FU LI, ZHI-YONG MAO, XIANG-JUN RAO, XIAO-MEI WANG, MAO-ZHONG MIN, LI-WEN QIU, ZHI-LI LIU, Bioresource Technol., 94 (2004) 193.
9. N. HAFEZ, A. S. ABDEL-RAZEK, M. B. HAFEZ, J. Chem. Technol. Biotechnol., 68 (1997) 19.
10. A. J. FRANCIS, J. B. GILLOW, C. J. DODGE, R. HARRIS, T. J. BEVERIDGE, H. W. PAPENGUTH, Radiochim. Acta, 92 (2004) 481.
11. P. SAR, S. K. KAZY, S. F. D'SOUZA, Intern. Biodeter. Biodeg., 54 (2004) 193.
12. T. S. PSAREVA, O. I. ZAKUTEVSKYY, N. I. CHUBAR, V. V. STRELKO, T. O. SHAPOSHNIKOVA, J. R. CARVALHO, M. JOANA NEIVA CORREIA, Colloids and Surfaces A: Physicochem. Eng. Aspects, 252 (2005) 231.
13. J. YANG, B. VOLESKY, Water Res., 33 (1999) 3357.
14. J. J. BYERLEY, J. M. SCHARER, A. M. CHARLES, Chem. Eng. J., 36 (1987) B49.
15. O. GENC, Y. YALCINKAYA, E. BUYUKTUNCEL, A. DENIZLI, M. Y. ARICA, S. BEKTAS, Intern. J. Miner. Process, 68 (2003) 93.
16. A. GODELITSAS, P. MISAELIDES, A. FILIPPIDIS, D. CHARISTOS, I. ANOUSIS, J. Radioanal. Nucl. Chem., 208 (1996) 393.
17. A. GODELITSAS, TH. ARMBRUSTER, Micropor. Mesopor. Mater., 61 (2003) 3.