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APPLICABILITY OF DIFFERENT KINDS OF YEAST BIOMASS TO LEAD REMOVAL FROM WATER

Aleksandra Duda-Chodak, Tomasz Tarko, Kamil Milotta

Chair of Fermentation Technology and Technical Microbiology
University of Agriculture in Krakow

Abstract

The aim of the study was to assess the possibility of using different yeast biomasses for lead removal from aqueous solution. The material for the study comprised baker's yeast (BY), spent waste brewer's yeast (WBY), and fodder yeast (FY), which can be easily obtained as production waste. An amount of each yeast biomass (BY, FY, or WBY) that equals 0.1 g of dry weight was suspended in 100 cm^3 of lead solution (concentration of 200, 500, or 1000 mg dm^{-3}) and biosorption was carried out for 20, 40, 60, 90, 120, 240, and 300 minutes. The concentration of lead remaining in solution was determined using atomic absorption spectroscopy. The lead uptake by yeast biomass was calculated using the mass balance equation for the biosorbent and the results were fitted to the Langmuir isotherm model. The yeast biomasses were able to remove more than 90% of lead present in solution within 20 minutes. With BY biomass, it was possible to reduce the lead level below 1 mg dm^{-3} from the initial lead solutions of 200 and 500 mg Pb dm^{-3}. The value of q_{max} and affinity parameter b, calculated for BY after 300 minutes of biosorption, were very high (1,250 mg Pb g^{-1} d.w. and 0.363, respectively). The best efficiency was achieved for BY when the initial concentration of lead was 500 mg dm^{-3}. The final concentration of the metal (after 300 minutes of sorption) was 0.66 mg dm^{-3}, which means that 99.86% of lead was removed from the solution by the biomass of baker's yeasts.

Key words: lead, toxicity, biosorption, waste treatment, yeasts, waste yeast, Langmuir isotherm.

Aleksandra Duda-Chodak, PhD, Chair of Fermentation Technology and Technical Microbiology, University of Agriculture in Krakow, ul. Balicka 122, 30-149 Krakow, Poland, phone: (48 12) 662 47 92, e-mail: aduda-chodak@ar.krakow.pl

MO¯LIWOŒÆ WYKORZYSTANIA RÓ¯NYCH TYPÓW BIOMASY DRO¯D¯Y DO USUWANIA OŁOWIU Z WODY

Abstrakt

Celem pracy by³a ocena mo¿liwoœci wykorzystania biomasy dro¿d¿owej do usuwania o³owiu z roztworów wodnych. Materia³ badawczy stanowi³y: dro¿d¿e piekarskie (BY), odpadowe dro¿d¿e browarnicze (WBY) oraz dro¿d¿e paszowe (FY), stanowi¹ce ³atwo dostêpny odpad produkcyjny. Iloœæ biomasy dro¿d¿y (BY, WBY, FY) odpowiadaj¹c¹ 0,1 g suchej substancji zawieszano w 100 cm^3 roztworu o³owiu (stê¿enie 200, 500 lub 1000 mg dm^{-3}) i przeprowadzano biosorpcjê przez 20, 40, 60, 90, 120, 240 i 300 minut. Stê¿enie o³owiu pozosta³ego w roztworze mierzono metod¹ adsorpcyjnej spektrometrii atomowej. Wielkoœæ ³adunku o³owiu usuniêtego przez biomasê dro¿d¿y wyliczano na podstawie równania równowagi masowej biosorbenta, a wyniki dopasowywano do izotermy Langmuira. Testowane dro¿d¿e usuwa³y z roztworu ponad 90% o³owiu w ci¹gu 20 min procesu. Jednak¿e jedynie zastosowanie BY umo¿liwia³o obni¿enie poziomu Pb poni¿ej 1 mg dm^{-3} z roztworów o wyjœciowym stê¿eniu 200 i 500 mg Pb dm^{-3}. Wartoœæ q_{max} oraz wspó³czynnik powinowactwa *b*, wyznaczone dla dro¿d¿y piekarskich po 300 min biosorpcji, wynosi³y odpowiednio 1250 mg Pb g^{-1} s.s. i 0,363. Najwiêksz¹ wydajnoœæ usuwania Pb wykazano stosuj¹c dro¿d¿e piekarskie (BY), gdy wyjœciowe stê¿enie o³owiu wynosi³o 500 mg dm^{-3}. Stê¿enie równowagowe metalu po 300 min sorpcji wynosi³o 0,66 mg dm^{-3}, co odpowiada usuniêciu przez biomasê dro¿d¿y piekarskich 99,86% o³owiu z roztworu.

S³owa kluczowe: o³ów, toksycznoœæ, biosorpcja, oczyszczanie œcieków, dro¿d¿e, dro¿d¿e odpadowe, izoterma Langmuira.

INTRODUCTION

Heavy metals present in water, soil and air are one of the most serious ecological problems for human and animal health. Lead, toxic at very low doses, is particularly dangerous to people. It is the only heavy metal with no known beneficial effect in the human body. No case of lead deficiency has ever been noted in the medical literature. Many other elements, such as Cr, Mn, Mo, Ni, and Se, although toxic at high concentration, are actually required at lower levels. The exposure to lead can affect every organ and, on a molecular level, it interferes with fundamental biochemical processes. Lead has the ability to mimic or inhibit calcium action and to interact with proteins. The most sensitive is the nervous system, especially of children. Neuropsychological defects and IQ lowering (Jusko et al. 2008) as well as encephalopathy and sensory deficits have been proved after exposure to lead (Damstra 1977, Patrick 2006). Lead exposure is one of the factors that contribute to the onset and development of anemia (Jain et al. 2005), hypertension (Korrick et al. 1999), ischemic heart disease (Jain et al. 2007), nephritis (Yu et al. 2004), diminished fertility in women (Chang et al. 2006) and hypospermia in men (de Rosa et al. 2003), and improper tooth and bone development (Damstra 1977, Patrick 2006). Women with blood lead level (BBL) 0.05-0.09 mg dm^{-3} were two to three times more likely to have

a spontaneous abortion than were women with BLL lesser than 0.05 mg dm^{-3} (Borja-Aburto et al. 1999).

Because lead has been freely used for centuries, it is now widespread in air, soil and water. There is no safe level of lead. The US Agency of Toxic Substances and Disease Registry (ATSDR) has not developed Minimum Risk Levels for lead, "because no thresholds have been demonstrated for the most sensitive effects in humans". Therefore, any exposure to lead is of potential concern.

The WHO has estimated that long-term ambient air concentration of 0.5-1.0 µg m^{-3} would mean that 98% of the population would have blood lead levels below 0.2 mg dm^{-3}. In 1984, the WHO established the maximum lead level in drinking water at 0.05 mg dm^{-3}. In 1993, this goal was revised to 0.01 mg dm^{-3}, to be met in 15 years. In Poland, the allowed level of lead in drinking water was diminished from 0.05 to 0.025 mg dm^{-3} (*The Regulation...* 2010). According to this regulation, starting form 1 January 2013 drinking water should contain less than 0.010 mg lead dm^{-3}. This has stimulated researchers' interest in the methods of lead elimination from the environment.

The main source of lead in drinking water is lead piping and lead-combining solders. The amount of lead that may dissolve in water depends on acidity (pH), temperature, water hardness and standing time of water. Secondary pollution from industry can contaminate water through the effluents produced. Lead is released into environment with wastes from facilities that produce lead-acid batteries, lead wire or pipes, lead-based paints, etc. Industrial wastewater from production of lead-acid batteries contains 10-60 mg dm^{-3} of lead. In urban waste, the Pb level is still high and ranges from 0.05 to 1.1 mg dm^{-3} (Klimiuk, £ebkowska, 2003). Proper treatment of industrial wastewaters, which are releasing lead into the aquatic and land systems, is very important. The conventional methods of lead removal from waste include chemical precipitations, conventional adsorption, ion exchange, membrane process, oxidation and reduction, and electro-remediation methods (Lesmana et al. 2009). However, most of the methods are expensive and not environment friendly because they generate secondary effluent (sludge), whose disposal is problematic.

Biosorption is a process that utilizes low-cost biosorbents to remove toxic heavy metals (Kratochvil, Volesky 1998). Biosorption has distinct advantages over the conventional methods such as low operating cost, selectivity for a specific metal, short operation time, reusability of biomaterial and no chemical sludge. There are a few systems which have already found application in industrial or technical operations. Some examples are: AMT-BIOCLAIM, AlgaSORB, BIO-FIX, B.V. Sorbex biosorbent, bioreactors with *Alcaligenes eutrophus* designed for biosorption of Zn(II), Cd(II) and other heavy metals or radionuclides, the use of *Citrobacter* or *Methylobacillus* biomass for treatment of uranium mining drains, thorium and radium removal from

mining wastewater and many others (BRIERLEY 1990, TSEZOS et al. 1997). The biomass of different microorganisms (bacteria, fungi, algae) has also been used for biosorption of different metals from aqueous solutions (SELATNIA et al. 2004, GONG et al. 2005, FARYAL et al. 2007, LESMANA et al. 2009). However, live cells need to be cultivated on special media and the cost of biosorbent grows. In the recent years, many biosorbent materials from agriculture have been utilized for heavy metal biosorption. Among easily available natural materials are different plant leaves (BENAÏSSA, ELOUCHDI 2007), coffee beans (KAIKAKE et al. 2007), fruit and vegetable pomace (KRÓL, NAWIRSKA 2003), chaff (HAN et al. 2005), oyster, almond and coconut shell, coconut fiber, and many more (LESMANA et al. 2009, QAISER et al. 2009, OPELOU et al. 2010).

The effect of different metals on *Saccharomyces cerevisiae* has already been examined by many authors (HETMAŃSKA et al. 1994, TUSZYŃSKI, MAKAREWICZ 2000, TUSZYŃSKI, PASTERNAKIEWICZ 2000). Their results have demonstrated a very rapid uptake of some metal ions by yeast cells. This has stimulated a growing interest in metal-yeast interaction and applicability of this phenomenon.

In the present research, the efficiency of lead removal from aqueous solution by three kinds of yeast biomasses has been evaluated. The selected yeasts are common in food industry and can be obtained as production waste.

MATERIAL AND METHODS

The material for the study consisted of 1) commercially available baker's yeast (BY) *Saccharomyces cerevisiae* (Lesaffre Bio-corporation S.A.); 2) spent waste brewer's yeast (WBY) *Saccharomyces cerevisiae* (waste from Tychy Brewery, after 4th passage); 3) fodder yeast (FY) *Rhodotorula* (the pure culture collection of the Department of Fermentation Technology and Technical Microbiology, University of Agriculture in Krakow, Poland).

Lead solutions

The stock solution of lead (100 g dm^{-3}) was prepared by using analytical grade lead acetate hydrate $(CH_3COO)_2Pb \cdot 3H_2O$ (POCh, Gliwice, Poland) and deionized water. An amount of 0.2, 0.5 and 1 cm^3 of stock solution was diluted in 100 cm^3 of deionized water to obtain working solutions of lead concentration 200, 500 and 1000 mg dm^{-3}, respectively.

Yeasts preparation

Baker's yeast (BY)

The yeast solution was prepared by diluting 1.000 g of baker's yeast in 10 cm^3 of physiological saline. Then, 200 cm^3 of yeast extract-peptone-dextrose medium (YEPD) was inoculated by 1 cm^3 of the yeast solution and incubated for 24 h in water bath at 30°C. The yeast biomass was obtained by centrifugation (5000 rpm, 5 min, 4°C, MPW-350R, MPW Med. Instruments, Poland) and washed with deionized water before further analysis.

Fodder yeast (FY)

Fodder yeasts of *Rhodotorula* genus were transferred on agar slants. Unhopped beer wort was diluted up to 9°Blg and sterilized (121°C, 10 min). An amount of 10 cm^3 of sterile wort was inoculated with one loop of yeast culture and incubated for 24 h at 30°C. The whole culture was then transferred into 100 cm^3 of sterile beer wort (9°Blg) and cultivation was conducted in a laboratory shaker (120 rpm, WU-4, Premed, Poland) for 24 h at 30°C. The yeast culture was then cooled (4°C, 3 h), centrifuged in aseptic condition (5000 rpm, 5 min, 4°C), and the yeasts obtained were washed with sterile deionized water.

Waste brewer's yeast (WBY)

Spent waste yeasts biomass (*Saccharomyces cerevisiae*) was obtained directly from Tychy Brewery (Poland) after 4^{th} passage (it was treated as waste). The yeast biomass was kept at 4°C for about 72 h until analysis.

The estimation of dry weight of yeasts

In each type of yeast biomass, the dry weight content was determined with a moisture analyzer (MAC50, Radwag, Poland).

Biosorption experiments

The amount of particular yeast biomass (BY, FY, or WBY) that equals 0.1 g of dry weight was suspended in 100 cm^3 of lead solution (concentration of 200, 500, or 1000 mg dm^{-3}) in an Erlenmeyer flask and incubated with continuous shaking (200 rpm) at room temperature (RT). After 20, 40, 60, 90, 120, 240, and 300 minutes, the mixture was centrifuged (5000 rpm, 5 min, RT) and clear supernatant was transferred into disposable tubes. The concentration of lead remaining in the supernatant was determined using atomic absorption spectroscopy (AAS) (Varian AA 240 FS, Varian Inc. Agilent Technologies). Eight replicates were performed for each time-point.

Calculations

The lead uptake by yeast biomass was calculated using the following mass balance equation for the biosorbent (VOLESKY 2004):

$$q = [V (C_0 - C_f)] / S,$$

where:

q – lead uptake at equilibrium (mg Pb g^{-1} biosorbent dry weight);
V – volume of metal-bearing solution contacted (batch) with the biosorbent (dm^3);
C_0 – initial concentration of metal in solution (mg dm^{-3});
C_f – final concentration of metal in solution (mg dm^{-3});
S – dry weight of biosorbent added (g).

In the preliminary experiments (initial metal concentration ranged 50-1000 mg dm^{-3}), the Langmuir and the Freundlich models were utilized to explain the experimental data (VOLESKY 2004). In all the analyzed cases, the correlation coefficient (r) for the Langmuir isotherm was higher than for the Freundlich isotherm. The experimentally determined equilibrium isotherms were compared with the theoretical Langmuir and Freundlich isotherms. An example of the results of this comparison is shown in Figure 1, which demonstrates that the Langmuir model yielded better representation of the experimental data. This is in accordance with many references that have demonstrated that the Langmuir model fits better to results of heavy metal biosorption by microorganisms (HOLAN, VOLESKY 1994, ÖZCAN et al. 2009, QAISER et al. 2009, VELMURUGAN et al. 2010). This model is based on the hypothesis that the uptake occurs on a homogenous surface by monolayer sorption without interaction between adsorbed molecules. It is expressed as:

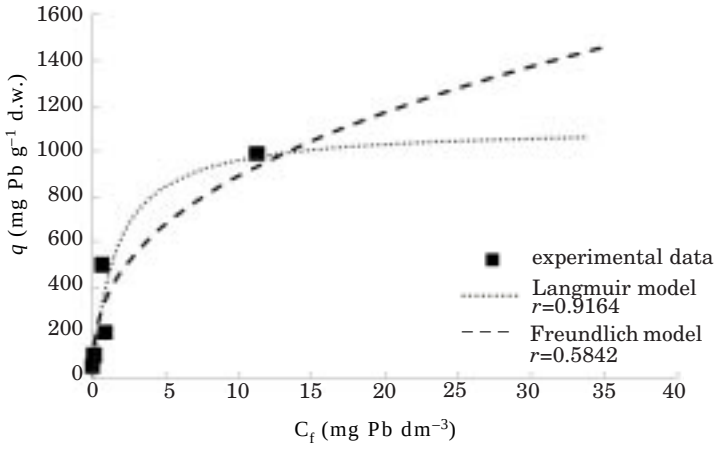

Fig. 1. Fitting of the experimental data to the theoretical (Freundlich and Langmuir model) equilibrium sorption isotherms: C_f – lead concentration at equilibrium, q – lead uptake at equilibrium, r – correlation coefficient

$$C_f/q = 1/q_{max} \cdot C_f + 1/(q_{max} \cdot b),$$

where:

q_{max} – represents the maximum biosorption capacity (mg Pb g^{-1} d.w.);
b – is an affinity parameter, related to the energy of biosorption.

In the experiments performed in this study, the initial concentration of lead varied from 200 to 1000 mg dm^{-3}, while the volume of lead solution and quantity of biosorbent were constant (respectively, 0.1 dm^3 and 0.1 g d.w.). Knowing these values, q was calculated and the plot C_f/q against C_f was drawn. The linear regression was used to determine the equation of best-fitted line, and the values of q_{max} and b were calculated (if possible). The results were taken into account only if the correlation coefficient was higher than r=0.7.

Statistical analysis

The results were shown as an arithmetic mean (± standard deviation) of eight replicates. A single-factor Analysis of Variance test (ANOVA) with a *post hoc* Tukey test was applied to perform statistical analysis. Kolmogorov-Smirnov test was applied to examine the normality of distribution.

RESULTS AND DISCUSSION

The level of lead was reduced significantly after biosorption with each type of yeast biomass independently from the initial lead concentration (p<0.05). The kinetics of the concentration changes was different but most lead was taken up within the first 20 minutes of the process. Moreover, all kinds of yeast biomass used in the study were able to remove more than 90% of lead present in the solution within 20 minutes (Table 1). These results are supported by literature references, suggesting that 95% of metal is removed by microorganisms within 30 minutes (Volesky et al. 1993, Gong et al. 2005).

The fodder yeasts were the most efficient biosorbent in solutions of lead concentration of 200 mg dm^{-3} when the efficiency was evaluated after 20 minutes. However, when the time of biomass contact with heavy metal was longer, the maximum uptake of lead (99.56%) was achieved by baker's yeast. Similar results were obtained for high concentration metal solution (1000 mg dm^{-3}); after 20 min the FY were more efficient than BY, but after 300 min the uptake of lead was almost the same (98.88% and 98.84%, respectively). It should be highlighted that only BY was able to reduce the lead level below 1 mg dm^{-3} from initial lead solutions of 200 and 500 mg Pb dm^{-3}.

Table 1

The efficiency of lead biosorption process by analyzed yeast at the initial lead concentration (C_0) [mg Pb dm^{-3}] and time of process (t) [min], final concentration of lead – C_f [mg Pb dm^{-3}] (arithmetic mean ± SD, n = 8) after biosorption and lead uptake at equilibrium – q [mg Pb g^{-1} d.w.]

t	C_0	BY		WBY		FY	
		C_f	q	C_f	q	C_f	q
20	200	19.62 ± 2.43 ^{a}	180.38	13.31 ± 0.43 ^{a,b}	186.69	9.16 ± 2.37 ^{a}	190.84
40		18.17 ± 1.26 ^{a}	181.83	10.29 ± 0.65 ^{c}	189.71	7.01 ± 1.33 ^{c,b}	192.99
60		8.23 ± 0.42 ^{b}	191.77	9.75 ± 2 67 ^{c}	190.25	7.40 ± 0.85 ^{a,b,d}	192.60
90		4.33 ± 0.53 ^{c}	195.68	9.54 ± 0.67 ^{c}	190.46	8.67 ± 1.48 ^{a,b}	191.33
120		1.04 ± 0.13 ^{d}	198.96	10.42 ± 3.71 ^{a}	189.58	4.42 ± 0.38 ^{e}	195.59
240		1.78 ± 0.15 ^{d}	198.22	10.55 ± 0.46 ^{b,c}	189.45	5.33 ± 0.21 ^{c,e}	194.67
300		0.88 ± 0.09 ^{d}	199.12	8.67 ± 1.31 ^{c}	191.33	5.98 ± 0.19 ^{c,d,e}	194.02
20	500	38.01 ± 1.36 ^{a}	461.99	27.54 ± 1.70 ^{a}	472.46	47.17 ± 3.68 ^{a}	452.83
40		38.47 ± 1.37 ^{a}	461.53	30.29 ± 2.27 ^{a,b}	469.72	25.77 ± 2.46 ^{b}	474.23
60		20.15 ± 1.83 ^{b}	479.85	30.04 ± 1.53 ^{a,a}	469.96	23.30 ± 1.47 ^{b,c}	476.70
90		0.94 ± 0.09 ^{c}	499.06	30.79 ± 2.14 ^{b}	469.21	21.52 ± 1.56 ^{c}	478.48
120		3.60 ± 0.41 ^{d}	496.40	30.78 ± 2.18 ^{b}	469.22	14.23 ± 2.56 ^{d}	485.77
240		1.29 ± 0.15 ^{c,d}	498.71	31.41 ± 1.68 ^{b}	468.60	12.63 ± 0.78 ^{d,e}	487.37
300		0.66 ± 0.05 ^{c}	499.35	23.06 ± 1.54 ^{c}	476.95	10.39 ± 0.50 ^{e}	489.61
20	1000	83.71 ± 5.09 ^{a}	916.29	60.27 ± 3.08 ^{a,b}	939.73	52.35 ± 1.95 ^{a}	947.65
40		79.12 ± 2.69 ^{b}	920.88	64.43 ± 3.57 ^{a}	935.57	62.73 ± 1.90 ^{b}	937.27
60		78.63 ± 2.59 ^{b}	921.37	60.80 ± 2.54 ^{a,b}	939.20	60.49 ± 2.50 ^{b}	939.51
90		38.68 ± 2.49 ^{c}	961.32	57.34 ± 2.51 ^{b,c}	942.66	55.91 ± 2.98 ^{a}	944.09
120		48.29 ± 2.17 ^{d}	951.72	56.40 ± 2.66 ^{b,c}	943.60	43.65 ± 4.64 ^{c}	956.36
240		30.39 ± 2.41 ^{e}	969.61	55.11 ± 3.57 ^{c}	944.89	24.89 ± 1.88 ^{d}	975.11
300		11.25 ± 1.43 ^{f}	988.76	53.63 ± 2.97 ^{c}	946.37	11.58 ± 1.42 ^{e}	988.42

BY – baker's yeasts, WBY – waste beer yeasts, FY – fodder yeasts *a,b,c,d…* – the same letters denote the lack of statistical significance ($p < 0.05$) between different time-points within the same kind of yeast biomass used for biosorption of particular concentration of lead

The results obtained in this study are very promising. FARYAL et al. (2007) analyzed the potential of *Aspergillus niger* biomass to remove lead from aqueous solutions. In solutions containing 1000 mg Pb dm^{-3}, the maximum lead biosorption observed on day 3 was 92.04% (for *A. niger* RH 17) and 92.72 (*A. niger* RH 18). These strains removed 204.57 and 206.04 mg Pb g^{-1} of dried biomass, respectively. In our studies, the lead uptake was 980, 946, and 988 mg of Pb per gram of dried BY, WBY and FY biomass, respectively.

Table 2

The Langmuir isotherm parameters (q_{max} and b) for lead biosorption by baker's (BY), waste beer (WBY), and fodder yeast (FY) biomasses depending on the biosorption process duration (t)

T (min)	BY			WBY			FY		
	q_{max} (mg g^{-1} d.w.)	b	r	q_{max} (mg g^{-1} d.w.)	b	r	q_{max} (mg g^{-1} d.w.)	b	r
20	*NC*	*NC*	*NC*	*NC*	*NC*	*NC*	*NS*	*NS*	*NS*
40	*NC*	*NC*	*NC*	3333	0.005	0.984	2000	0.014	0.919
60	1667	0.018	0.969	*NS*	*NS*	*NS*	2000	0.014	0.987
90	1250	0.085	0.791	*NS*	*NS*	*NS*	3333	0.007	0.950
120	1000	0.250	0.999	*NS*	*NS*	*NS*	1667	0.029	0.996
240	1111	0.204	0.961	*NS*	*NS*	*NS*	*NC*	*NC*	*NC*
300	1250	0.363	0.920	3333	0.007	0.997	*NC*	*NC*	*NC*

NC – q_{max} and b were not calculated, the Langmuir isotherm did not fit
NS – the correlation coefficient (r) was below 0.7

Also, in the study of PARVATHI et al. (2007) Langmuir constant q_{max} for *Saccharomyces cerevisiae* was calculated. However, the maximum concentration of lead used in that study was only 100 mg dm^{-3}, and the q_{max} was established at the level of 55.71 mg g^{-1}. In many available references, the maximum possible amount of lead ion adsorbed per unit weight of biosorbent was much lower than in our study; 137 mg g^{-1} of *Streptomyces rimosus* biomass (SELATNIA et al. 2004), 85.86 mg g^{-1} and 61.35 mg g^{-1} of *Phanerochaete chrysosporium* (SAY et al. 2001 and YETIS et al. 2000, respectively), 50.9 mg g^{-1} of *Enterobacter* sp. (LU et al. 2006). Our results also exceeded the lead uptake determined in the study of HOLAN and VOLESKY (1994) for different marine algae.

The value of q_{max} and affinity parameter b (Table 2) calculated for by after 300 minutes of biosorption were very high (1250 mg Pb g^{-1} d.w. and 0.363, respectively, r = 0.920). For example, q_{max} for groundnut hull was only 31.54 mg Pb g^{-1} (QAISER et al. 2009).

The best efficiency was achieved for BY when the initial concentration of lead was 500 mg dm^{-3}. The final concentration of the metal (after 300 minutes) was 0.66 mg dm^{-3}, which means that 99.86% of lead had been removed by the biomass of baker's yeasts. The biosorption process conducted by fodder yeasts could be presented by the Langmuir isotherm for only the first 120 minutes, and was characterized by a low affinity parameter. The longer biosorption (240 and 300 min) did not fit the above model, so q_{max} could not be calculated.

It was also demonstrated that the biosorption process conducted with baker's yeasts ran through two phases, with the first one finishing after 60 min. Further studies should be done to determine if the second phase is the bioaccumulation process. Another possibility is that cells become destroyed and new metal binding sites appear.

When q_{max} was calculated, its extremely high values (3,333 mg Pb g^{-1} d.w.) were obtained for spent waste beer yeasts after 300 minutes of biosorption. However, affinity parameter *b* was low (0.007) and it can be seen that in each experiment variant, the amount of lead removed from solution by WBY was the lowest. Concluding, among the analyzed kinds of yeast, WBY was the weakest biosorbent. This could have been due to the stress produced on yeast cells during fermentation in a brewery. Moreover, small gas bubbles were observed on the surface of cell in the WBY biomass. They could have significantly reduced the contact surface between the metal and cell wall. Both BY and FY were cultivated in laboratory conditions and were "non-stressed". The biphasic biosorption process can suggest that baker's yeast cells were alive and in good condition, and the bioaccumulation could take place (TUSZYÑSKI, PASTERNAKIEWICZ 2000). In spent waste beer yeasts, only physical adsorption on cell structures (mainly cell walls) probably occurred.

CONCLUSIONS

In the present research, it has been proven that yeast can be used for lead removal as a highly efficient biosorbent. Among the analyzed different yeast biomasses, the best results were achieved for baker's yeast. The lead uptake obtained in the study and the calculated values of q_{max} were higher than those demonstrated by other researchers when biosorption was performed with moulds or bacteria. The experimental data of lead biosorption by yeast biomass fit better the Langmuir than the Freundlich isotherm model.

Further research should concentrate on methods of modification of biomass in order to improve its properties. Next, the process of desorption as well as the evaluation of possible numbers of sorption/desorption cycles of the same biomass usage could be conducted.

REFERENCES

BENAÏSSA H., ELOUCHDI M.A. 2007. *Removal of copper ions from aqueous solutions by dried sunflower leaves.* Chem. Eng. Proc., 46: 614-622.

BORJA-ABURTO V.H. HERTZ-PICCIOTTO I., LOPEZ M.R., FARIAS P., RIOS C., BLANCO J. 1999. *Blood lead levels measured prospectively and risk of spontaneous abortion.* Am. J. Epidemiol., 150: 590-597.

BRIERLEY C.L. 1990. *Bioremediation of metal-contaminated surfaces and groundwaters.* Geomicrobiology, 8: 201-223.

CHANG S.-H., CHENG B.-H., LEE S.-L., CHUANG H.-Y., YANG C.-Y., SUNG F.-C., WU T.-N. 2006. *Low blood lead concentration in association with infertility in women.* Environ. Res., 101: 380-386.

CHEN C., WANG J. 2008. *Removal of Pb^{2+}, Ag^{+}, Cs^{+} and Sr^{2+} from aqueous solution by brewery's waste biomass.* J. Hazard. Mat., 151: 65-70.

DAMSTRA T. 1977. *Toxicological properties of lead.* Environ. Health Perspect., 19: 297-307.

DE ROSA M., ZARRILLI S., PASANO L., CARBONE U., BOGGIA B., PETRETTA M., MAISTO A., CIMMINO F., PUCA G., COLAO A., LOMBARDI G. 2003. *Traffic pollutants affect fertility in men.* Hum. Reprod., 18(5): 1055-1061.

FARYAL R., SULTAN A., TAHIR F., AHMED S., HAMEED A. 2007. *Biosorption of lead by indigenous fungal strains.* Pak. J. Bot., 39(2): 615-622.

GONG R., DING Y., LIU H., CHEN Q., LIU Z. 2005. *Lead biosorption and desorption by intact pretreated Spirulina maxima biomass.* Chemosphere, 58: 125-130.

HAN R., LI H., LI Y., ZHANG J., XIAO H., SHI J. 2006. *Biosorption of copper and lead ions by waste beer yeast.* J. Hazard. Mat., B137: 1569-1576.

HAN R., ZHANG J., ZOU W., SHI J., LIU H. 2005. *Equilibrium biosorption isotherm for lead ion on chaff.* J. Hazard. Mat., B125: 266-271.

Rozporz¹dzenie Ministra Zdrowia, Dz.U. nr 72, poz. 466 z dnia 20.04.2010 r., zmieniaj¹ce rozporz¹dzenie w sprawie jakoœci wody przeznaczonej do spo¿ycia przez ludzi [The Regulation of the Ministry for Health, Journal of Law no 72, item 466, of 20 April 2010, amending the regulation on potable water quality].

HETMAÑSKA B., TOMASIK P., TUSZYÑSKI T. 1994. *The metal-metal interactions in biological systems.* Part II *Saccharomyces cerevisiae.* Water Air Soil Poll., 74: 281-288.

HOLAN Z.R., VOLESKY B. *1994. Biosorption of lead and nickel by biomass of marine alga.* Biotechnol. Bioeng., 43: 1001-1009.

JAIN N.B., LADEN F., GULLER U., SHANKAR A., KAZANI S., GARSHICK E. 2005. *Relation between blood lead levels and childhood anemia in India.* Am. J. Epidemiol., 161: 968-973.

JAIN N.B., POTULA V., SCHWARTZ J., VOKONAS P.S., SPARROW D., WRIGHT R.O., NIE H., HU H. 2007. *Lead levels and ischemic heart disease in a prospective study of middle-aged and elderly men: the VA normative aging study.* Environ. Health Perspect., 115: 871-875.

JUSKO T.A., HENDERSON JR. C.R., LANPHEAR B.P., CORY-SLECHTA D.A., PARSONS P.J., CANFIELD R.L. 2008. *Blood lead concentrations < 10 µg/dL and child intelligence at 6 years of age.* Environ. Health Perspect., 116(2): 243-248.

KAIKAKE K., HOAKI K., SUNADA H., DHAKAL R.P., BABA Y. 2007. *Removal characteristics of metal ions using degreased coffee beans: Adsorption equilibrium of cadmium(II).* Biores. Technol., 98: 2787-2791.

KLIMIUK E., £EBKOWSKA M. 2003. *Biotechnologia w ochronie œrodowiska [Biotechnology in environmental protection].* Wyd. Nauk. PWN, Warszawa, 131-198. (in Polish)

KORRICK S.A., HUNTER D.J., ROTNITZKY A., HU H., SPEIZER F.E. 1999. *Lead and hypertension in a sample of middle-aged women.* Am. J. Public Health, 89(3): 330-335.

KRATOCHVIL D., VOLESKY B. 1998. *Advances in the biosorption of heavy metals.* Trends Biotechnol., 16(7): 291-300.

KRÓL S., NAWIRSKA A. 2003. *Usuwanie jonów metali ciê¿kich na wyt³okach owocowych w uk³adach dynamicznych [Removal of ions of heavy metals on fruit pomace in dynamic systems]*. Acta Sci. Pol. Technol. Aliment., 2(1): 21-29. (in Polish)

LESMANA S.O., FEBRIANA N., SOETAREDJO F.E., SUNARSO J., ISMADJI S. 2009 *Studies on potential applications of biomass for the separation of heavy metals from water and wastewater*. Biochem. Eng. J., 44: 19-41.

LU W.-B., SHI J.-J., WANG C.-H., CHAN J.-S. 2006. *Biosorption of lead, copper and cadmium by an indigenous isolate Enterobacter sp. J1 possessing high heavy-metal resistance*. J. Hazard. Mat., B134: 80-86.

OPELOU B.O., BAMGBOSE O., AROWOLO T.A., ADETUNJI M.T. 2010. *Utilization of biomaterials as adsorbents for heavy metals' removal from aqueous matrices*. Sci. Res. Ess., 5(14): 1780--1787. http://www.academicjournals.org/sre/PDF/pdf2010/18Jul/Opelou et al.pdf

ÖZCAN A.S., TUNALI S., AKAR T., ÖZCAN A. 2009. *Biosorption of lead(II) ions onto waste biomass of Phaseolus vulgaris L.: estimation of the equilibrium, kinetic and thermodynamic parameters*. Desalination, 244: 188-198.

ÖZER A., ÖZER D. 2003. *Comparative study of biosorption of Pb(II), Ni(II) and Cr(IV) ions onto S. cerevisiae: determination of biosorption heat*. J. Hazard. Mat., B100: 219-229.

PARVATHI K., NAGENDRAN R., NARESHKUMAR R. 2007. *Lead biosorption onto waste beer yeast by-product, a means to decontaminate effluent generated from battery manufacturing industry*. Electron. J. Biotechnol., 10(1), http://www.ejbiotechnology.info/content/vol10/issue1/full/13/

PATRICK L. 2006. *Lead toxicity, a review of the literature*. Part I. *Exposure, evaluation, and treatment*. Altern. Med. Rev., 11(1): 2-22.

QAISER S., SALEEMI A.R., UMAR M. 2009. *Biosorption of lead(II) and chromium(VI) on groundnut hull: Equilibrium, kinetics and thermodynamics study*. Electron. J. Biotechnol., 12 (4), http://www.ejbiotechnology.info/content/vol12/issue4/full/6/

SAY R., DENIZLI A., ARÝCA M.Y. 2001. *Biosorption of cadmium(II), lead(II) and copper(II) with the filamentous fungus Phanerochaete chrysosporium*. Biores. Technol., 76: 67-70.

SELATNIA A., BOUKAZOULA A., KECHID N., BAKHTI M.Z., CHERGUI A., KERCHICH Y. 2004. *Biosorption of lead (II) from aqueous solution by a bacterial dead Streptomyces rimosus biomass*. Biochem. Eng. J., 19: 127-135.

TSEZOS, M., 1997. *Biosorption of lanthanides, actinides and related materials*. In: *Biosorbents for metal ions*. (eds.) WASE, J., FORSTER, C. TAYLOR & Francis Ltd., London.

TUSZYÑSKI T., PASTERNAKIEWICZ A. 2000. *Bioaccumulation of metal ions by Saccharomyces cerevisiae*. Pol. J. Food Nutr. Sci., 9/50 (4): 31-39.

TUSZYÑSKI T., MAKAREWICZ M. 2000. *Zinc ion concentration in brewery yeast cells*. Chem. In¿. Ekol., 7(10): 1106-1116.

VELMURUGAN N., HWANG G., SATHISHKUMAR M., KIE CHOI T., LEE K.-J., OH B.-T., LEE Y.-S. 2010. *Isolation, identification, Pb(II) biosorption isotherms and kinetics of a lead adsorbing Penicillium sp. MRF-1 from South Korean mine soil*. J. Environ. Sci., 22(7): 1049-1056.

VOLESKY B. 2004. *Equilibrium biosorption performance*. In: *Sorption and biosorption* (ed. B. VOLESKY), BV-Sorbex, Inc., Montreal, Canada http://biosorption.mcgill.ca/publication/book/6.1-4w(103-16).pdf

VOLESKY B., MAY H., HOLAN Z.R. 1993. *Cadmium biosorption of Saccharomyces cerevisiae*. Biotechnol. Bioeng., 41: 826-829.

YETIS U., DOLEK A., DILEK F.B. OZCENGIZ G. 2000. *The removal of Pb(II) by Phanerochaete chrysosporium*. Wat. Res., 34(16): 4090-4100.

YU C.-C., LIN J.-L., LIN-TAN D.-T. 2004. *Environmental exposure to lead and progression of chronic renal diseases: a four-year prospective longitudinal study*. J. Am. Soc. Nephrol., 15: 1016-1022.