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Removal of lead from aqueous solution by walnut shell

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The paper deals with the study of nuts of European walnut (*Juglans regia*) arising as waste from the agricultural production for the removal of heavy metals from aqueous solutions. The suitability of the given biosorbent was verified through the determination of its adsorption capacity (equilibrium) and rate (kinetics) of adsorption of the studied metal (lead). The shells of the European walnut were first activated by 0.1 M of HCl and 0.1 M of NaOH, while the activation by sodium hydroxide was more effective than activation by HCl. In order to identify the most suitable method of activation for the given biosorbent, biosorption of European walnut shells activated by NaOH at concentrations of 0.01, 0.1, 1 and 2 mol/L was further studied, and the time of activation was 5, 15, 30 and 45 min. The output analyses imply that the most effective chemical treatment of the biosorbent is the activation of European walnut shells by means of NaOH at concentration of 1 mol/L for 30 min. However, also activation by sodium hydroxide at concentration of 1 mol/L for 15 min is suitable, which is very important with regard to the economy in time.

Key words: Biosorption, heavy metals, adsorption capacity, biosorption kinetics, isotherms, walnut shell, biosorbent.

INTRODUCTION

An increase in the application of heavy metals in the industrial activities results in the production of waste water that contains high values of toxic heavy metals and their presence thus causes environmental risks. Dissolved and liberated metals in the environment may accumulate in live tissues through the food chains (Ahluwalia and Goyal, 2007; Kyoung-Woong and So-Young, 2006). Therefore, health problems may arise, manifested both on an acute and chronic base (Kaduková and Virčíková, 2003). Bivalent lead is in many aspects similar to calcium and therefore can operate competitively in mitochondrial respiration or with neurological functions. Interaction of lead and nucleic acids leads to decrease or increase of protein synthesis. Lead reduces the ability of transfer ribonucleic acids to bind to ribosomes (Landis and Yu, 2004).

Currently, there are a number of technologies that are used in the removal of heavy metals from waste water. Classical (conventional) methods of water treatment are, for example, chemical precipitation, membrane filtration, chemical oxidation or reduction, etc., but they are expensive. Experts thus strive to identify economically more affordable methods of heavy metal removal from aqueous solutions. A lot of attention is paid to the study of biological material as potential biosorbent of heavy metals (Romera et al., 2007).

During bio-sorption it comes to a physico-chemical interaction between a metal and functional cell walls groups, independently of metabolism (Romera et al., 2007). Biosorption belongs to a progressive technology of environmental chemistry, because it seems to be a good alternative for removal of heavy metals from aqueous

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solutions. It can also possibly contribute to existing sewage treatment technologies. The advantage of its usage is particularly with waste water after dilution, since this method is suitable for capture of lower toxic metals concentration (below 100 mg/L of metal) or for additional purification of already treated water to achieve concentrations complying with emission limits (Švecová et al., 2005).

Many studies by various authors point out that waste biomass of vegetable is a potential biosorbent for removal of heavy metals from aqueous solutions because vegetable material, represented particularly by cellulose and lignin, is a significant bearer of reactive groups which can bind metal ions.

De Carvalho et al. (1999) was interested in utilization of higher plants (*Cormobionta*) as heavy metals sorbent. They have studied possibilities of biosorption of copper from aqueous solution by dry tea leaves (*Theka sinensis*) and other Brazilian plants (*Aspidosderma tomentosum*, *Qualea parviflora*, *Maitena truncata*). They discovered that sorption places are most likely located on biomass fibres, which is made of dextrans. These places provide indeed groups C-O and C=O, that are to be found in these fibres. It is also probable, that binding sites are to be found at other leaf types (de Carvalho et al., 1999).

Previous laboratory batch experiments of *Medicago sativa* (alfalfa) indicated that the African shoots population had an excellent ability to bind copper(II) and nickel(II) ions from aqueous solution. Batch pH profile experiments for the mentioned ions indicated that the optimum pH for metal binding is approximately 5.0. Time dependency experiments for the metal ions showed that for all the metals studied, binding to the African alfalfa shoots occurred within five minutes. Binding capacity experiments revealed the following amounts of metal ions bound per gram of biomass: 7.1 mg Cd, 7.7 mg Cr(III), 43 mg Pb(II), and 4.9 mg Zn(II). However, no binding occurred for chromium (VI). Nearly all of the metals studied were recovered by treatment with 0.1 M HCl, with the exception of chromium (III) (Gardea-Torresdey et al., 1996).

Low et al. (1995) studied banana pith (*Musacea zingiberales*) was evaluated for its ability to sorb metal ions from electroplating waste and synthetic solutions under both batch- and continuous-flow conditions. Biosorption of selected heavy metals (Pb, Cu, Ni, Cr, Zn) was observed at optimum pH value 4-5. The equilibrium data followed the Langmuir isotherm model with maximum capacities of 8.55 and 13.46 mg/g for Cu in electroplating waste and synthetic solution respectively. Competitive studies showed that the affinity of metal sorption was in the order Pb(II)>Cu(II)>Ni(II)>Cr(III)>Zn(II), (Low et al., 1995). Waste biomass fruit stones such as plum (*Prunus domestica*) stones showed potential for removal of selected heavy metals (Cd, Pb, Cr, Cu) from aqueous solution. The study included activation of garden plum stones by HCl and NaOH. It emerged from the output analysis that the most effective is sorbent activation via

0.1 M NaOH for 15 min at grain size of 0.5-1 mm. The maximum sorption capacities of the various metal components on plum stones biomass could be prioritized in order from high to low as: Pb(II) > Cu(II) > Cd(II) > Cr(III), (Kováč et al., 2008). Schiewer and Patil (2008) found out that citrus fruit peel is a suitable cadmium sorbent thanks to presence of pectin in the peel structure. Uptake was rapid with equilibrium reached after 30-80 min depending on the particle size (0.18-0.9 mm).

Laboratory experiments of Shukla and Pai (2005) proved that lignocellulosic fibre, jute, was assessed for adsorption of heavy metal ions like Cu(II), Ni(II) and Zn(II) from their aqueous solutions. Thus, the dye loaded jute fibres showed metal ion uptake values of 8.4, 5.26 and 5.95 mg/g for Cu(II), Ni(II) and Zn(II), respectively, while the corresponding values for oxidised jute fibres were 7.73, 5.57 and 8.02 mg/g, as against 4.23, 3.37 and 3.55 mg/g for unmodified jute fibres. The desorption efficiency, regenerative and reuse capacity of these adsorbents were also assessed for three successive adsorption-desorption cycles (Shukla and Pai, 2005).

Kobya et al. (2005) investigated sorption capacity of apricot stone for the following metals: Ni(II), Co(II), Cd(II), Cu(II), Pb(II), Cr(III) and Cr(VI). Highest adsorption occurred at 1-2 for Cr(VI) and 3-6 for the rest of the metal ions, respectively. Adsorption capacities for the metal ions were obtained in the descending order of Cr(VI) > Cd(II) > Co(II) > Cr(III) > Ni(II) > Cu(II) > Pb(II). Cimino et al. (2000) carried out removal of Cd(II), Zn(II), Cr(III), Cr(VI) from aqueous solution by usage of hazel nut shell as a biosorbent. Batch equilibrium tests showed that the metal sorption was dependent on both pH and surface loading. Experiments by mixed solutions showed that more Cr(III) ions were removed than both Cd(II) and Zn(II) ions.

Besides the biological material as potential biosorbent, many synthetic sorbents can strongly adsorb heavy metal from aqueous solutions. Li et al. (2009) studied poly(aniline-co-5-sulfo-2-anisidine) nanosorbents and the results show that the maximum Hg-ion sorption capacity on the particulate nanosorbents can even reach 2063 mg of Hg per gram of sorbent. Novel copolymer nanoparticles were easily synthesized with a polymerization yield of 59.3% by an oxidative precipitation polymerization of aniline (AN) and *m*-sulfophenylenediamine (SP) in HCl without any external stabilizer. The AN/SP (70:30) copolymer particles have the highest Hg(II) adsorbance and adsorptivity of 497.7 mg/g and 98.8%, respectively, which are much higher values than those of other materials. The copolymer should be very useful in the fabrication of cost-effective conductive nanocomposite with low percolation threshold and in removal of toxic metallic ions from waste water (Lü et al., 2007).

Huang et al. (2006) examined synthetic sorbents such as poly(*p*-phenylenediamine) (PpPD) and poly(*m*-phenylenediamine) (PmPD) for their strong ability to adsorb lead ions from aqueous solution. According to the Langmuir equation, the maximum adsorption capacities

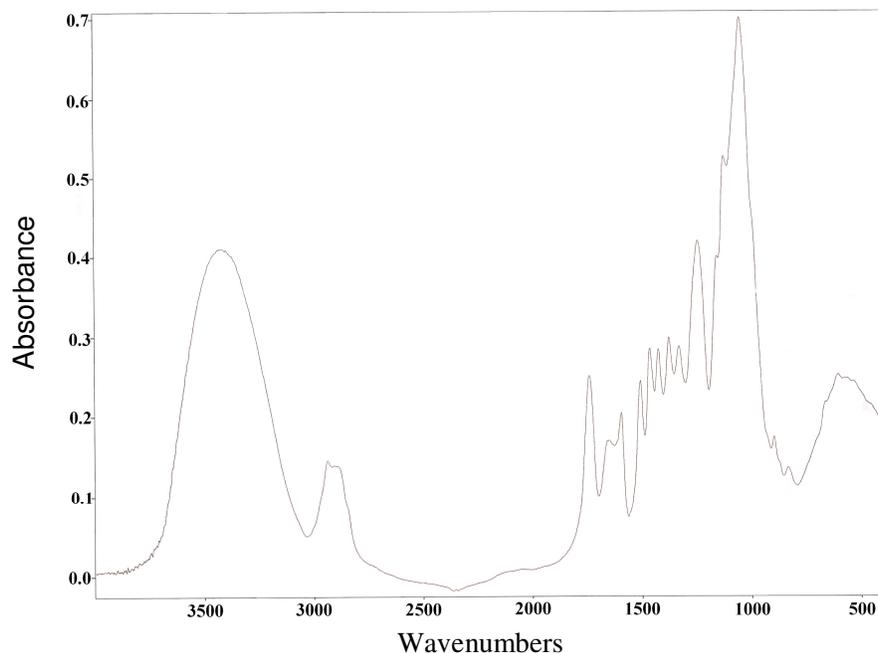


Figure 1. FT-IR spectrum of European walnut shells.

of lead ions onto PpPD and PmPD microparticles at 30 °C are 253.2 and 242.7 mg/g, respectively. A series of batch experiment results showed that the PpPD microparticles possess an even stronger capability to adsorb lead ions than the PmPD microparticles, but the PmPD microparticles, with a more-quinoid-like structure, show a stronger dependence of lead-ion adsorption on the pH and temperature of the lead-ion solution (Huang et al., 2006).

Plant material applicable as biosorbent should be classified in the grain size between 0.1 and 3 mm. Better functionality and applicability of the biosorbent in the process of biosorption should be ensured by its chemical treatment. Biosorbent is then immediately capable of biosorption of ions from metals in aqueous solutions (Volesky, 2003). Biosorbent should be cheap and easily available in large quantities. Moreover, it should contain reactive groups in its structure, which are responsible for the isolation of metals from solutions. This implies that it is convenient to be aware of the chemical composition of a cell wall of the applied biosorbent (Volesky, 2003).

MATERIALS AND METHODS

Biosorbent characteristics

Shells of the European walnut nuts (*Juglans regia*) were used as biosorbent. The nut of the European walnut is hard, chemically inert, nontoxic and largely available plant material. A shell of the European walnut nut is formed by three basic substances, namely cellulose (40.5%), hemicellulose (23.8%) and lignin (20.3%). The elementary content of elements determined in a shell of the

European walnut is as follows: 51.2% carbon; 5.8% hydrogen; 0.1% nitrogen; 0.14% sulphur; 0.34% phosphorus; 0.51% potassium; 0.12% calcium and 0.22% magnesium and a low quantity of mineral compounds, which are labelled as ash content in the European walnut (0.9%). On the European walnut shell cell wall surface there is a large quantity of various functional groups that are able to trap and bond more metals from solutions. The reactive groups in the biosorbent formulas significant for the metal bonds were determined using the method of Fourier transform onto the absorption infra-red spectrum (FT-IR).

All biosorbent samples showed similar FT-IR spectra development, therefore individual reactive (functional) groups in the structure of walnut shell were determined by FT-IR spectrum sample of the biosorbent activated by NaOH (Figure 1). With this sample it came to the highest efficiency of lead removal during kinetics and equilibrium studies.

In the infra-red spectrum shown in Figure 1 there is an apparent wide band with a maximum of 3400 cm^{-1} in the area $3050\text{--}3600\text{ cm}^{-1}$. This spectrum sphere is characteristic for --OH group (alcohols). Alcohols also have an apparent intensive absorption band of valence vibration of C--O bond around 1050 cm^{-1} . A characteristic band of valence vibrations of C--H bond at $2800\text{--}3000\text{ cm}^{-1}$ is typical for the absorption bands of C--H in methyl compounds and methylene group in the lignin structure (McMurry, 2007). In the European walnut cell wall structure there are also carbonylic groups, for which there is a characteristic band in the area $1670\text{ to }1780\text{ cm}^{-1}$. In the area $1450\text{ to }1600\text{ cm}^{-1}$ there are a number of bands of medium intensity, which are caused by complex vibration movements of an aromatic ring and characterize aromatic compounds (McMurry, 2007).

Biosorbent treatment

The nut of the European walnut (*J. regia*) was first cleaned from the kernel. For better applicability in grinding, shells were crushed to the size of about 2-5 cm.

Thermal treatment of biosorbent surface

The pre-treated shells of the European walnut (crushing) were first dried at the laboratory temperature for 24 h prior to grinding. To prevent a sticky effect in screening, the samples are dried at the temperature of 105 °C till constant mass for 4 h prior to screening. The European walnut samples were also thermally treated at 105 °C till constant mass for 4 h before and after activation of the sorbent by activating agents.

Grain-size treatment of biosorbent

Crushed and dried shells of European walnut were screened into grain-size classes 2-3 mm and 1-2 mm.

Chemical activation of biosorbent

The chemical activating agent was 0.1 M HCl and 0.1 M NaOH. The chemical activation by 0.1 M HCl took 90 min at 180 rpm with biosorbent concentration of 10 g/L. In case of activation by 0.1 M NaOH, the process lasted 15 min at 180 rpm with biosorbent concentration of 10 g/L. Then, each material was washed three times in redistilled water to avoid any trace of the used activating agent. As a standard, for adsorption tests we used European walnut shells which underwent identical physical and thermal treatment, but redistilled water was used instead of activating agent.

In order to identify the most suitable method of activation for the given biosorbent and determination of limits when the sorption is already insignificant and when it does not take place, further conditions of European walnut shell biosorption were studied but activated by more suitable activating agent of sodium hydroxide. Apart from the original concentration of NaOH 0.1 mol/L also the concentration of 0.01, 1 and 2 mol/L were used. The original time of activation of 15 min was expanded to 5, 30 and 45 min.

Modelling of adsorption kinetics

For the study of lead kinetics, model lead solutions of initial concentrations of 100 and 200 mg/L were used. A standard $Pb(NO_3)_2$ by company PENTA, Czech Republic, was used for preparation of model lead samples. The prepared samples of model metal solutions with biosorbent of concentration 10 and 20 g/L were agitated at 180 rpm. In the individual time intervals (0, 30, 60, 180, 300, 420, 540, 720 and 1440 min) biosorbent samples were drawn and later filtered and analyzed by the method of atomic absorption spectrometry.

Effects of pH on adsorption

For the study of pH value effect on biosorption, we chose the observed range of pH values 2-6 (that is, 2, 3, 4, 5 and 6). The input concentration of the model lead solution was 200 mg/L and biosorbent concentration in the metal solution was 20 g/L. Adding nitric acid of concentration 0.1 mol/L or sodium hydroxide of concentration 0.1 mol/L always achieved the required pH value. Acid or alkali was added in such amounts so as not to alter the solution volume.

The treated samples of model metal solutions with sorbent were agitated in a shaking incubator at 180 rpm. Then, the biosorbent samples were filtered, and the input and steady state (residual final) concentrations of the studied metals were analyzed using the method of atomic absorption spectrometry.

Modelling of adsorption isotherms

For the modelling of adsorption isotherms we used the working solutions with lead contents of 40, 60, 80, 120 and 200 mg/L. A standard $Pb(NO_3)_2$ by company PENTA, Czech Republic, was used for preparation of model lead samples. The model metal samples with biosorbent of concentration 20 g/L were agitated in a shaking incubator at 180 rpm till the uptake equilibrium was stabilized. In the time of establishing the uptake equilibrium which was set on the basis of kinetics study (12 h), samples were drawn, filtered and analyzed using the method of atomic absorption spectrometry. Based on the acquired values, lead adsorption was calculated according to the following Equation (1) (Volesky, 2003):

$$q = \frac{V \cdot (C_i - C_f)}{S} \quad (1)$$

where q is the equilibrium metal uptake (mg/g), V the volume of metal solution (l); C_i and C_f are the initial and final metal concentration (mg/L) and S is the weight of biosorbent (g).

The best treatment to express lead biosorption from model solutions in all the biosorbent samples was the relation for modified Langmuir isotherm of the first type Equation (2):

$$\frac{C_f}{q} = \frac{C_f}{q_{\max}} + \frac{1}{q_{\max} b} \quad (2)$$

where q is the equilibrium metal uptake (mg/g), q_{\max} is the maximum equilibrium metal uptake (mg/g), b is the Langmuir constant and C_f is the final metal concentration (mg/L). Adsorption lead isotherms were graphically created with help of the "OriginLab" programme.

RESULTS AND DISCUSSION

Evaluation of adsorption kinetics

In the study of lead kinetics with the initial lead solution concentration of 100 mg/L elimination of total lead from aqueous solution occurred in thirty minutes. This initial lead concentration thus appears unsuitable. Based on this fact, only measured values from experiments were further evaluated, where the initial lead solution concentration of 200 mg/L was used. At the same time, it was identified that for the lead kinetics study the most suitable concentration of biosorbent is 20 g/L, because the highest efficiency of lead removal from the model solution was registered at this concentration. Under the set conditions, equilibrium was achieved in all the biosorbent samples after 12 h.

It is apparent from the lead adsorption kinetics study (Figure 2) in dependence on the method of biosorbent chemical treatment that the highest adsorption capacity (8.69 mg/g) for lead in the time of equilibrium stabilization was registered in the sorbent activated by 0.1 M NaOH and grain size 2-3 mm (O3/1-2/NaOH), when the lead concentration dropped from the original value of 206 to 32 mg/L, which is also clear from the curve steepness in Figure 3. The lowest decrease in lead in the time of equilibrium stabilization was

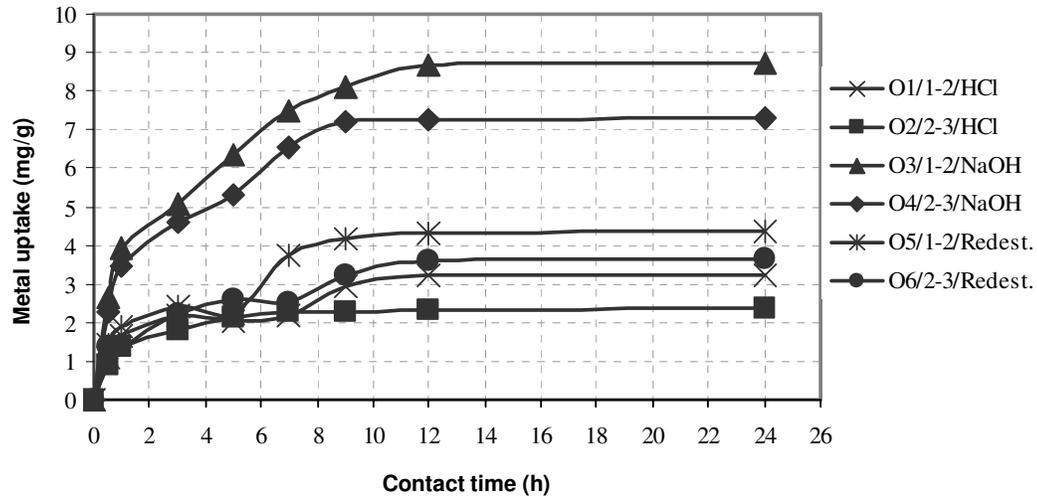


Figure 2. Lead adsorption kinetics. Explanatory notes: O – walnut; 1-2 mm and 2-3 mm – grain size; HCl, NaOH, Redist. – activating agent; q – equilibrium metal uptake of lead.

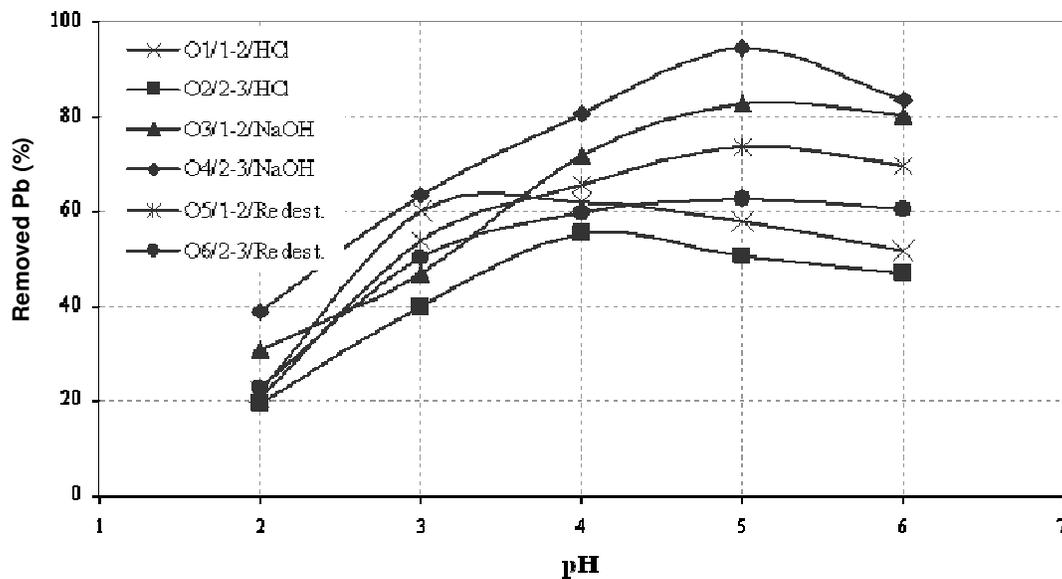


Figure 3. The impact of pH value on the lead biosorption process by European walnut. Explanatory notes: O – walnut; 1-2 mm and 2-3 mm – grain size; HCl, NaOH, Redist. – activating agent.

demonstrated using hydrochloric acid of 0.1 mol/L concentration as an activating agent in the sorbent grain size of 2-3 mm (O2/2-3/HCl), when the lead content in the model solution fell from the original value of 197 to 121 mg/L.

Evaluation of pH effects on adsorption

Figure 3 implies that lead biosorption was low at the initial pH values of 2-3. The lead content in the biosorbent

samples ranged from 19-39%. The low metal biosorption (up to 39%) below pH value 3 can be explained by the prevailing presence of H_3O^+ ions that successfully occupy the majority of the binding sites after the competitive fight for active sites with metal ions. As a result, the metal ions have worse binding capacity onto biosorbents than H_3O^+ ions and the biosorbent adsorption capacity is reduced. Efficiency of removed lead occurred from pH 3 and over, which was probably caused by the falling concentration of H_3O^+ and the reactive sites could be occupied with metal ions. This action is directly proportional up to the specific

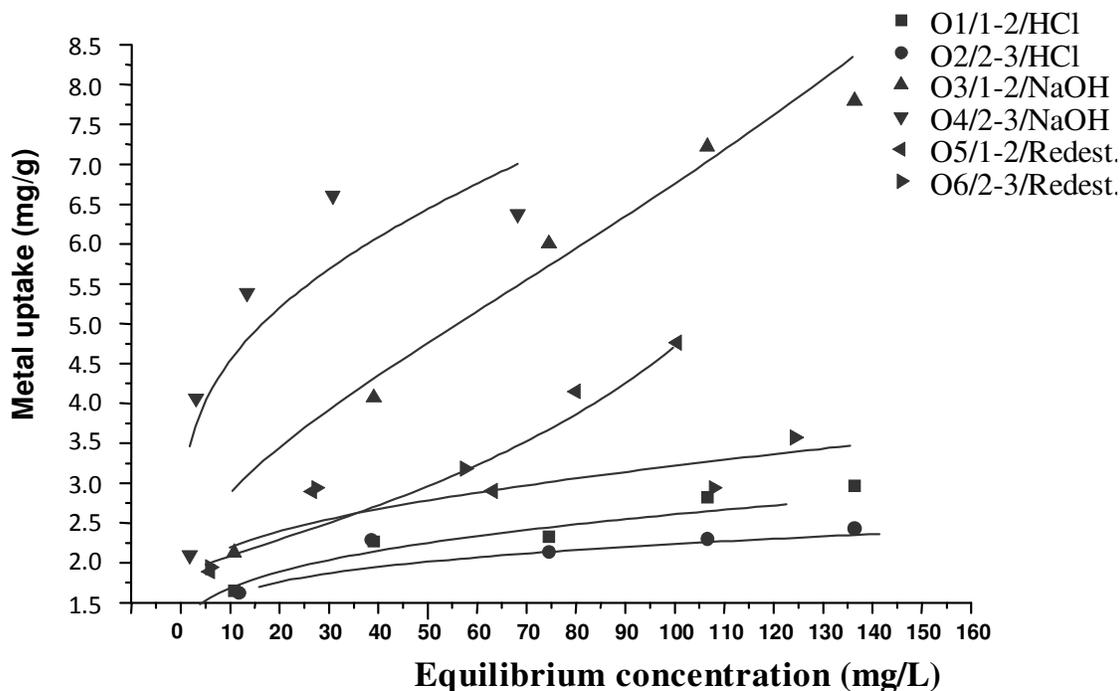


Figure 4. Adsorption isotherms for lead. Explanatory notes: O – walnut; 1-2 mm and 2-3 mm – grain size; HCl, NaOH, Redist. – activating agent.

pH value that is individual for each metal and each environment, and during which metal ion adsorption is maximum.

The maximum lead uptake was in case of the biosorbent activated by 0.1 M HCl for both the grain sizes at the value of pH 4, while the lead content in the biosorbent sample of grain size 1-2 mm (O1/1-2/HCl) was 62% and the European walnut sample of grain size (O2/2-3/HCl) it was 55%. In the sorbent activated by 0.1 M NaOH in both the grain sizes the most lead was removed from the model solutions at pH 5. The lead content in the biosorbent samples of grain size 1-2 mm (O3/1-2/NaOH) was 83% at pH 5 and in the biosorbent samples of grain size 2-3 mm (O4/2-3/NaOH) it was 95% of lead. The maximum lead uptake in the check European walnut sample which is activated by redistilled water was at pH 5. At this pH value the lead content for the sample of grain size 1-2 mm (O5/1-2/Redist.) was 74%.

Evaluation of adsorption isotherms

The most information on the efficiency of the given adsorption is provided by the study of equilibrium between the solid phase (sorbent) and liquid phase (model metal solution). The equilibrium study in this system (model metal solution-biosorbent) determines the

distribution of substance that is dissolved in the solution and the capacity of the own biosorbent (Volesky, 2007). It is apparent from Figure 4 that the highest adsorption capacity for lead was in case of the European walnut sample activated by 0.1 M NaOH. As for the grain size in the sample activated by 0.1 M NaOH the biosorbent sample of grain size 1-2 mm (O3/1-2/NaOH) was more successful, while the maximum calculated theoretical value of lead uptake was 7.79 mg/g. The lead adsorption capacity values by sorbent activated by NaOH ranged from 2.13 to 7.79 mg/g.

The lowest maximum adsorption capacity (2.43 +mg/g) in the time of equilibrium stabilization was demonstrated using hydrochloric acid of 0.1 mol/L concentration as an activating agent in the sorbent grain size of 2-3 mm (O2/2-3/HCl). Table 1 states the Langmuir isotherm parameters and relevant statistical information for Pb sorbent system. The lead uptake evaluation from the European walnut sample model solutions activated individually by all the stated concentrations of a more suitable activating agent NaOH, that is, 0.01, 0.1, 1 and 2 mol/L NaOH, is shown in Figure 5.

The highest adsorption capacity for lead was registered with the European walnut shells sample which was activated by sodium hydroxide of 1 mol/l concentration for 30 minutes (1/30). However, activation by sodium hydroxide at the concentration of 1 mol/L for 15 min (1/15) and concentration of 2 mol/L for 45 min (2/45) was also suitable (Figure 5). The lead adsorption capacity

Table 1. Langmuir isotherm parameters and relevant statistical information for Pb sorbent system.

| Sample description | Langmuir | | |
|--------------------|------------------|------------|--------|
| | q_{max} (mg/g) | b (L/mg) | R^2 |
| O1 / 1-2 / HCl | 2.97 | 0.029 | 0.9801 |
| O2 / 2-3 / HCl | 2.43 | 0.037 | 0.9957 |
| O3 / 1-2 / NaOH | 7.79 | 0.122 | 0.9969 |
| O4 / 2-3 / NaOH | 6.38 | 0.115 | 0.9994 |
| O5 / 1-2 / Redist. | 4.26 | 0.034 | 0.9801 |
| O6 / 2-3 / Redist. | 3.57 | 0.043 | 0.9668 |

Explanatory notes: O – walnut; 1-2 mm and 2-3 mm – grain size; HCl, NaOH, Redist. – activating agent; q_{max} - maximum equilibrium metal uptake (mg/g); b - Langmuir constant; R^2 – regression.

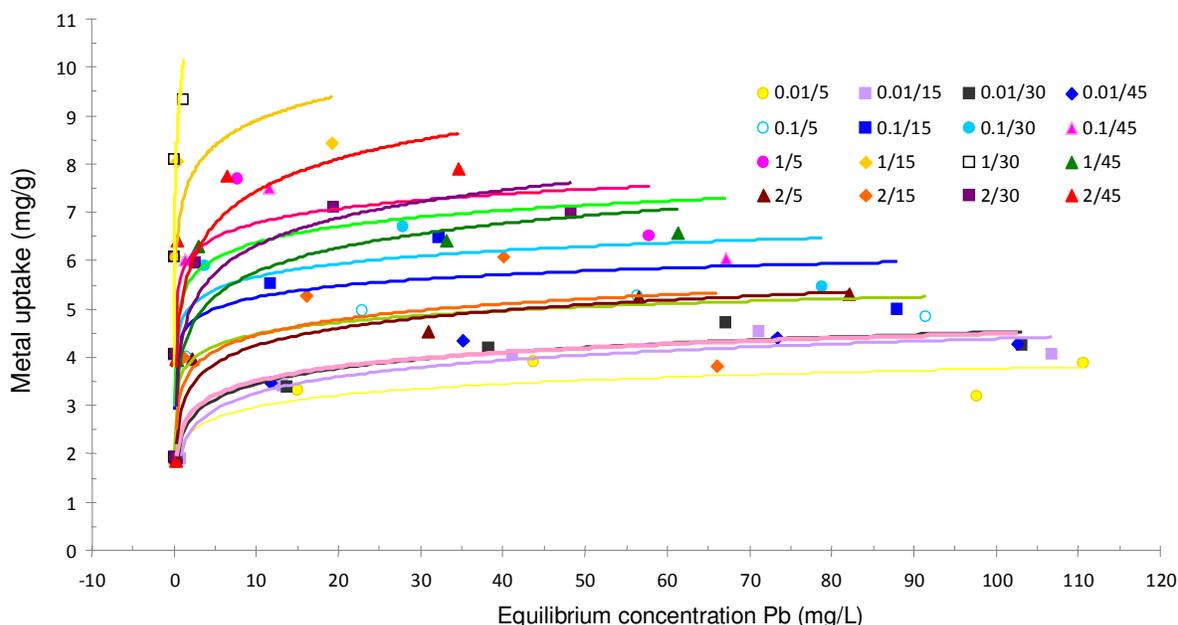


Figure 5. Adsorption isotherms for lead in dependence on the biosorbent activation by all the concentrations of NaOH; Explanatory notes: 0.01, 0.1, 1, 2 – concentration of activating agent NaOH; 5, 15, 30, 45 - the time of activation.

values by sorbent activated by NaOH ranged from 3.90 to 9.34 mg/g. Table 2 gives the Langmuir isotherm parameters and relevant statistical information for Pb sorbent system.

Conclusion

Usage of biosorbent for metal sorption bears a lot of advantages compared to classic methods such as chemical precipitation, membrane filtering, chemical oxidation or reduction, etc. Above all, it is an effective and economically affordable method which uses biological waste material from various industrial processes, such as

food processing industry and agriculture (plum and apricot stones, hazelnut shells, citrus fruit flesh, alfalfa or tea leaves, and other). Price of the sorbent is influenced by sorbent’s availability. It can also vary depending on the required level of biological material processing. Another advantage of biosorption is that it does not come to creation of sewage sediments such as with classical methods, which - even after cleaning - contain decreased amount of contaminants and it is necessary to treat it further on to avoid negative impacts on the environment. Biosorption technology also does not require either any special equipment/apparatus or operating conditions. Arrangement of the process in columns is the same as when using commercial ion exchanger or activated

Table 2. Lead biosorption isotherm parameters for all the samples.

| Sample description | Langmuir | | |
|--------------------|-------------------|------------|--------|
| | q_{\max} (mg/g) | b (l/mg) | R^2 |
| 0.01/5 | 3.90 | 0.227 | 0.9775 |
| 0.01/15 | 4.52 | 0.179 | 0.9935 |
| 0.01/30 | 4.72 | 0.325 | 0.9927 |
| 0.01/45 | 4.41 | 0.481 | 0.9986 |
| 0.1/5 | 5.26 | 9.226 | 0.9974 |
| 0.1/15 | 6.46 | 14.53 | 0.9926 |
| 0.1/30 | 6.68 | 14.03 | 0.9955 |
| 0.1/45 | 7.50 | 12.38 | 0.9988 |
| 1/5 | 7.69 | 17.96 | 0.9996 |
| 1/15 | 8.44 | 16.64 | 0.9999 |
| 1/30 | 9.34 | 19.41 | 0.9995 |
| 1/45 | 6.56 | 0.722 | 0.9999 |
| 2/5 | 5.30 | 0.513 | 0.9963 |
| 2/15 | 6.07 | 0.636 | 0.9467 |
| 2/30 | 7.10 | 0.918 | 0.9998 |
| 2/45 | 7.89 | 1.086 | 0.9997 |

Note: 0.01; 0.1; 1; 2 – concentration of activating agent; 5, 15, 30, 45 – time of activation, q_{\max} – maximum equilibrium metal uptake (mg/g); b – Langmuir constant; R^2 – regression.

coal/carbon, and therefore is easily applicable in industry. Based on lead and cadmium sorption capacity studies it can be stated that walnut fruit is a suitable sorbent for heavy metals such as lead. Depending on the way of sorbent's chemical modification it follows that the most suitable activating agent for lead biosorption is sodium hydroxide. On the contrary, hydrochloric acid appears as an unsuitable activating agent. The most convenient physical treatment is grinding and screening of the sorbent into grain size class of 2-3 mm. The most effective chemical treatment is the activation of the biosorbent by means of sodium hydroxide at concentration of 1 mol/L for 30 min. However, also activation by sodium hydroxide at concentration of 1 mol/L for 15 min is suitable, which is very important with regard to the economy in time.

Biosorbents such as walnut shells as well as other waste material of vegetable origin have sorption properties though, but these are lower compared to sorbents produced for industrial purposes or compared to synthetic sorbents. In spite of this it is possible to make use of them everywhere clean technologies necessary (free of chemical procedures) and also when a cheap purification/treatment option (reclamation) is needed.

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