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Remediation of Pb(II) using *Pleurotus sajor-caju* isolated from metal-contaminated site

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ABSTRACT

Wastewater pollution has always been a major problem throughout the world. The lack of suitable water used for drinking and other activities has declined through the years. A white rot fungus named as *Pleurotus sajor-caju* was isolated from soil of a heavy metal-contaminated site and was used for the remediation of Pb(II) ions contamination from aqueous solution as well as wastewater streams. *Pleurotus sajor-caju* was immobilized into Ca–alginate granules to enhance its Pb(II) uptake capacity and to increase its ease of separation from contaminated samples. The experimental variables investigated during the present study were pH, dose, initial metal concentration, time, temperature, and co-metal ions. The maximum Pb(II) uptake potential of immobilized *Pleurotus sajor-caju* was 227.08 mg/g. Sulfuric acid and ethylenediaminetetraacetic acid (EDTA) (0.1 M) were found to be the better desorbing agents in comparison to acetic acid, hydrochloric acid, and sodium hydroxide. Change in solution temperature did not affect Pb(II) uptake capacity from 30 to 60˚C. A complete thermodynamic approach to Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass is provided in this study. The separation factor (R_L), surface coverage (θ), free energy of adsorption (ΔG°_{ads}), enthalpy (ΔH°), and entropy (ΔS°) presented in current manuscript for adsorption of Pb(II) ions by fungal biomass provides an accurate basis for predicting the thermodynamic properties and phase equilibria for adsorption from wastewaters.

Keywords: Pleurotus sajor-caju; Pb(II); White rot fungus; Biosorption; Wastewater; Desorption

1. Introduction

Pollution of many lakes and rivers is being caused by wastewater produced from domestic households, industrial, and agricultural practices. As urbanization expands and cities grow, the need to deal with the environmental impact becomes even more important to ensure sustainable development [1]. This also entails handling increasing volumes of wastewater. Efficient wastewater management is needed for handling always increasing volumes of wastewater [2]. Heavy metals from contaminated

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waste water may cause a serious threat to human health. Heavy metals are non-biodegradable unlike organic pollutants. These metals have been extensively studied and their effects on human health were regularly reviewed by international bodies such as the World Health Organization. Humans are using heavy metals for thousands of years. Although, since long time, several adverse health effects of heavy metals have been known, exposure to heavy metals continues. In some parts of world, exposure to heavy metals is even increasing particularly in less-developed countries. Heavy metal emissions have declined in most developed countries over the last 100 years [3,4]. Heavy metals have the ability to concentrate and accumulate in living organisms through food chain [5–12]. The general human population is exposed to Pb(II) from water, air, and food in roughly equal proportions [13–19]. Children are particularly susceptible to Pb(II) exposure due to the permeable blood–brain barrier and high gastrointestinal uptake because their growing bodies absorb more Pb(II) than adults do and their brains and nervous systems are more sensitive to the damaging effects of Pb(II) [15]. Pb(II) levels in blood in children should be reduced below the levels so far considered acceptable as recent data indicating that there may be neurotoxic effects of Pb(II) at lower levels of exposure than previously anticipated [20–27].

Traditionally, heavy metal removal is being carried out using complexation, ion exchange, membrane processes, electrolysis, electrochemical processes, reverse osmosis, oxidation–reduction, and precipitation. Often, traditionally used methods for heavy metals removal involve high operational cost and capital investment and usually become ineffective in many cases when heavy metal concentrations needed to reduce less than 50 ppm [28–30]. Biosorption is a term which involves the use of biological materials to control and detoxify environmental contaminants. White rot fungi are a versatile biosorption group as they can grow under extreme conditions of nutrient availability, pH, and temperature as well as high metal concentration. A large percentage of fugal cell wall material also shows excellent metal binding properties, playing a key role in heavy metal sorption [31].

The present research study was undertaken to investigate the Pb(II) uptake potential of *Pleurotus sajor-caju* collected from metal-contaminated site. Effect of various adsorption process variables including pH, dose, initial metal concentration, time, temperature, shaking speed, co-metal ions, and desorption was optimized.

2. Materials and methods

2.1. Reagents

All the chemicals and reagents used in the present study were of analytical grade and mainly purchased from Sigma–Aldrich Chemical Company, USA.

2.2. Micro-organism, media, and immobilization

Pleurotus sajor-caju cells were collected from soil obtained from metal-contaminated site (Changa Manga Forest, Kasur District, Pakistan). The cultures of *Pleurotus sajor-caju* were identified and multiplied in Mushroom Laboratory, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan. *Pleurotus sajor-caju* cells cultures were maintained on potato dextrose agar (PDA) slants. Seven-days old *Pleurotus sajor-caju* cultures grown on PDA slants were used to produce biomass using Vogel media. The composition of growth medium (g/L) was as follows: $MgSO_4\ 7H_2O$ (0.2), NH_4NO_3 (2.0), KH_2PO_4 (5.0), peptone (2.0), D-glucose (5.0), trisodium citrate (2.5), yeast extract (1.0), and $(NH_4)_2SO_4$ (4.0) [31]. After 72 h of growth at 30˚C, *Pleurotus sajor-caju* biomass was separated from Vogel media using vacuum filtration and fungal mycelia were killed by autoclaving at 121˚C for 30 min. The collected biomass was dried at 70˚C for 3 d and then ground into powdered form. Immobilization of *Pleurotus sajor-caju* biomass was carried out by following procedure: 1 g of ground *Pleurotus sajor-caju* biomass was mixed in a high-speed blender (Panasonic model MJ-W176P) with 2 g of Na–alginate dissolved in 100 mL of deionized distilled water (DDW). The solution containing *Pleurotus sajor-caju* biomass suspension was introduced in the form of drops into 0.1 M $CaCl_2$ solution using a narrow-sized burette. The average size of bead was found to be 3.55 mm.

2.3. Biosorption studies

During biosorption studies of white rot fungi, fixed volume of metal solution (100 mL) was used to evaluate the effect of various experimental parameters. The effect of pH (1–4.5), dose (0.5–3 g/L), initial Pb(II) concentration (25–1,000 mg/L), contact time (15–240 min), temperature (30–60˚C), shaking speed (0–200 rpm), and co-metal ions (0–400 mg/L) were optimized during the present study. The flasks were agitated on an orbital rotating shaker (PA 250/25. H) at single constant shaking speed in each batch experiment. The sample flasks were removed from the orbital shaker on completion of each experiment, and the aqueous solutions were filtered using Whatman filter paper (#40) to remove *Pleurotus sajor-caju* beads. Appropriate blanks were run during optimization of experimental variables.

2.4. Column study

A Pyrex glass column having 75 cm height and 1.8 cm internal diameter was packed with 10 g of immobilized *Pleurotus sajor-caju* biomass; to assure even circulation of Pb(II) solution and to prevent the flotation of immobilized *Pleurotus sajor-caju* biomass beads, the glass column was filled on both sides with glass beads. Glass wool was placed between the biomass beads and the glass beads at the bottom end of the column. The bottom of the column was sealed using a rubber stopper with a single bore. The connection in the column setup was made using Tygon tubing. The down flow mode was selected to operate the column. The continuous flow rate of aqueous phase maintained using a peristaltic pump was 2.5 mL/min. The bed depth and bed volume were approximately 53 cm and 120 mL, respectively. After predetermined time intervals, the concentration of Pb(II) ions in the eluent phase was measured.

2.5. Desorption

EDTA, CH_3COOH, H_2SO_4, HCl, and NaOH were used as desorbing agent at a concentration of 0.1 *N* solution.

2.6. Metal ions solution

Stock Pb(II) solution (1,000 mg/L) was prepared by dissolving 1.5980 g of analytical grade PbN_2O_6 in one liter of de-ionized distilled water (DDW). Metal ions solutions of required concentrations were prepared by appropriate dilution of the stock solution (1,000 mg/L) with DDW.

2.7. Determination of Pb(II) contents in the metal-contaminated solutions

The samples of wastewater were analyzed for determination of Pb(II) contents using a Perkin Elmer AAnalyst 300 atomic absorption spectrophotometer equipped with an air-acetylene burner, deuterium arc background corrector. Polypropylene flasks and glassware were kept immersed in chromic acid overnight before the analysis procedure. Before use, polypropylene flasks and glassware were rinsed several times with DDW.

2.8. Metal ion uptake capacity

Pb(II) ion uptake by *Pleurotus sajor-caju* was calculated by the concentration difference method. The initial metal concentration, C_0 (mg/L) and metal concentrations at equilibrium time, C_e (mg/L) were determined using AAS analysis. The metal uptake of *Pleurotus sajor-caju* q (mg/g) was calculated from the mass balance as follows:

$$q = (C_0 - C_e)V/1,000 \times W$$

Where V = volume of the solution in mL, W = mass of the sorbent in g.

2.9. Statistical analysis

Three independent determinations were made for each variable to calculate standard deviation.

3. Results and discussion

3.1. Influence of initial pH

Solution pH controls not only the ionization of functional groups present on cell surface of biomass but also precipitation of metal ions in a pH-dependent phenomenon. Hence, optimization of pH is usually the first step in metal uptake studies. In three ways, solution pH can influence metal uptake using biomaterials process: first, by affecting the configuration of the active ion-exchange sites; second, by controlling the ionic state of the sorbate in the solution; and third, extreme pH values could damage biomaterials cell structure. Effect of solution pH on uptake of Pb(II) is presented in Fig. 1(a) and (b). There was a prominent effect of pH on uptake of Pb(II) by *Pleurotus sajor-caju*. The maximum Pb(II) removal by immobilized *Pleurotus sajor-caju* was 192 ± 0.14 mg/g noted at pH 4.5. Thereafter, the adsorption percentage decreased in medium, perhaps, due to the formation of $Pb(OH)_2$ and soluble hydroxyl complexes such as $PbOH^+$, aqueous $Pb(OH)_2$, and $Pb(OH)^{3-}$. Formation of metal hydroxides made true sorption studies impossible beyond 4.5 pH.

3.2. Effect of biosorbent dose

Biosorbent dose is a crucial factor in metal sorption studies as it determines the sorbent and sorbate equilibrium of the aqueous system. To determine the influence of biosorbent dose on Pb(II) uptake by immobilized *Pleurotus sajor-caju*, biomass weight was varied from 0.05 to 0.3 g/100 mL at pH 4.5, 120 rpm

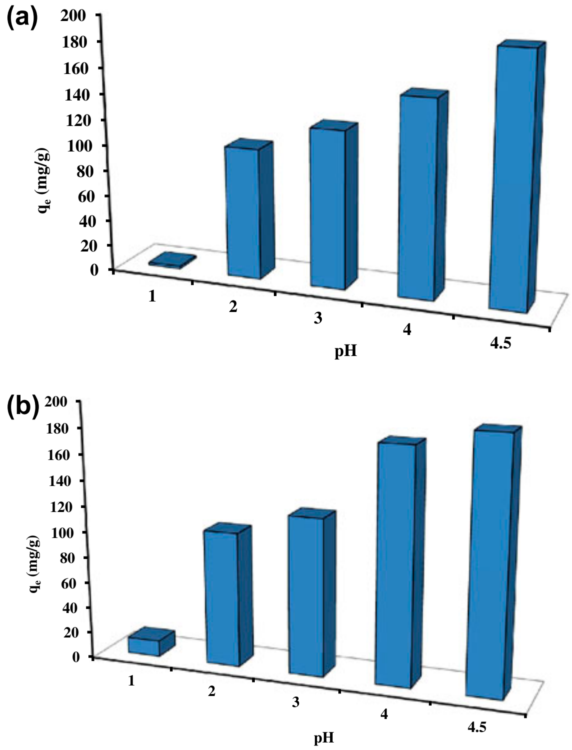

Fig. 1. Effect of solution pH on uptake of Pb(II) by *Pleurotus sajor-caju* dead cells. (a) native biomass and (b) immobilized biomass.

shaking speed and 30˚C (Fig. 2(a)). Uptake of Pb(II) using immobilized *Pleurotus sajor-caju* biomass decreased as biomass concentration was increased. Agglomeration of biomass cells and reduction in the inter-cellular distance result in decrease in biomass capacity. It means that more Pb(II) ions were adsorbed by biomass at low biomass concentrations when the inter-cellular distance was more. Under such conditions, cells have optimal electrostatic interaction which is a significant factor for metal ions uptake [32].

3.3. Effect of initial metal concentration

It is necessary to study the effect of metal ion concentration to evaluate the industrial applicability of biosorption process. Initial concentration of Pb(II) was varied from 25 to 1,000 mg/L and the results are shown in Fig. 2(b). It is clear from the results that Pb(II) uptake capacity of immobilized *Pleurotus sajor-caju* increased with increase in initial metal ion concentration until the saturation point was reached at 200 mg/L. The maximum Pb(II) uptake capacity (mg/g) by immobilized *Pleurotus sajor-caju* biomass was 222.9. The initial Pb(II)

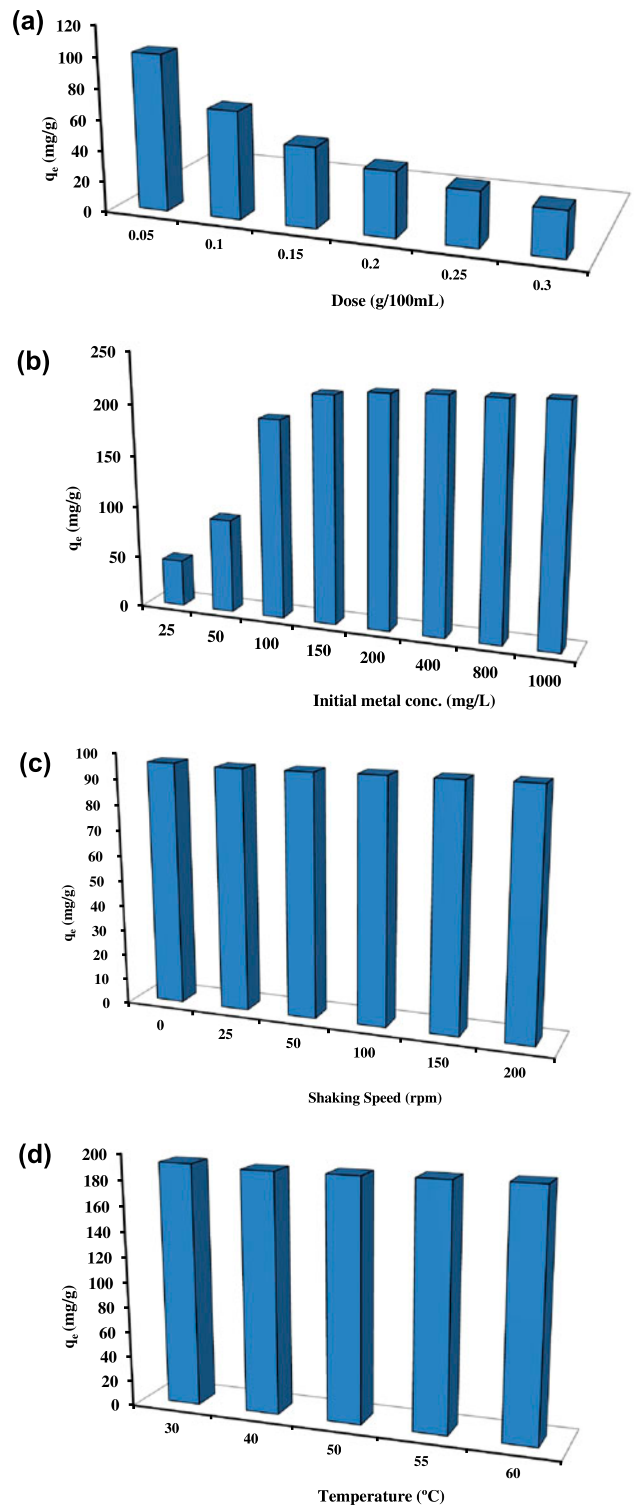

Fig. 2. Effect of various experiment variables on uptake of Pb(II) by immobilized *Pleurotus sajor-caju* dead cells (a) biomass dose; (b) initial metal concentration; (c) shaking speed; and (d) temperature.

Table 1
A comparison between Langmuir and Freundlich adsorption isotherm parameters for Pb(II) uptake by immobilized dead *Pleurotus sajor-caju* biomass

Langmuir isotherm parameters			Experimental value	Freundlich isotherm parameters			
q_{max} (mg/g)	K_L (L/mg)	R^2	q_{max} (mg/g)	q_{max} (mg/g)	K (mg/g)	$1/n$	R^2
181.81	1.13×10^{-1}	0.9997	178.36	223.68	48.85	0.2233	0.6266

concentration data was fitted to Langmuir and Freundlich sorption isotherm models (Table 1) to evaluate the nature of Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass. A comparison between Langmuir and Freundlich adsorption isotherm parameters for Pb(II) ions uptake by immobilized *Pleurotus sajor-caju* biomass showed that estimated q_{max} of Langmuir adsorption isotherm correlated well to the experimental q_{max} values. The value of correlation coefficient (R^2) for Langmuir adsorption isotherm model (0.9997) was also higher than Freundlich adsorption isotherm model (0.6266). The parameters of linear regression suggested that the Pb(II) adsorption by immobilized *Pleurotus sajor-caju* biomass was monolayer adsorption as described by Langmuir adsorption isotherm [32].

3.4. Effect of shaking speed

The metal ions uptake by biomass was evaluated varying the agitation rate from 0 rpm (without agitation) to 200 rpm, aiming at determining the optimal shaking rate (Fig. 2(c)). It is evident from Fig. 2(c) that the removal efficiency of Pb(II) ions by immobilized *Pleurotus sajor-caju* biomass was independent of agitation speed. It might be due to the immobilization of fungal biomass into beads which reduced the effect of agitation on metal adsorption.

3.5. Effect of temperature

The purpose of this experiment was to ascertain the effect of temperature on the sorption of Pb(II) by immobilized *Pleurotus sajor-caju* biomass. The effect of temperature on the Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass was investigated at five different temperatures (20–60°C) and the results are depicted in Fig. 2(d). The result revealed that there was no significant effect of temperature on Pb(II) biosorption by immobilized *Pleurotus sajor-caju* biomass from 20 to 60°C. This temperature independency for the Pb(II) adsorption process could be very useful for utilizing immobilized *Pleurotus sajor-caju* biomass for metal uptake from industrial effluents as the variable temperature of industrial effluents has previously been shown to affect the metal sorption process [22].

3.6. Effect of time

Contact time influences the treatment efficiency of the biosorption process. It was observed that equilibrium for Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass was attained after 120 min after this time the removal efficiency of Pb(II) was not changed significantly (Fig. 3).

Pb(II) ions rapid uptake occurred in first 15 min of contact. After equilibrium, the removal efficiency did not significantly change due to complete coverage of active sites [33]. Tables 2 and 3 represent the kinetic data of studies carried out on aqueous solutions in batch and continuous modes, respectively. As the volume of industrial effluents is usually large, it is good to carry out laboratory studies in continuous mode to get an idea regarding real-time adsorption. The results obtained for contact time experiments for aqueous solutions in batch mode were fitted to pseudo-first-order and pseudo-second-order kinetic models. A high value of correlation coefficient (R^2) and a close agreement between estimated and experimental q values

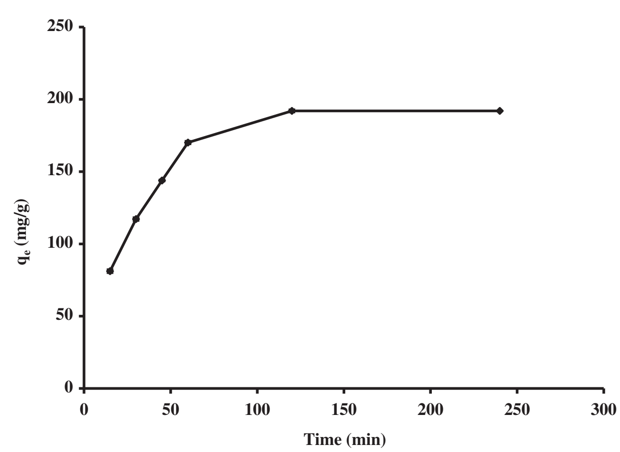

Fig. 3. Effect of time on uptake of Pb(II) by immobilized *Pleurotus sajor-caju* dead cells.

Table 2
A comparison between pseudo-first-order and pseudo-second-order kinetic models for Pb(II) uptake by immobilized dead *Pleurotus sajor-caju* biomass at various temperatures

	Pseudo-first-order kinetic model			Experimental value	Pseudo-second-order kinetic model		
Temp (ºC)	q_e (mg/g)	$K_{1,ads}$ (min^{-1})	R^2	q_e (mg/g)	q_e (mg/g)	$K_{2,ads}$ (g/mg min)	R^2
30	204.92	3.50×10^{-2}	0.9701	192.0	212.76	2.31×10^{-4}	0.9959
40	217.97	3.80×10^{-2}	0.9794	189.86	208.33	2.41×10^{-4}	0.9953
50	217.87	3.90×10^{-2}	0.9787	190.32	208.33	2.58×10^{-4}	0.9958
55	211.83	4.0×10^{-2}	0.9838	191.40	208.33	2.81×10^{-4}	0.9964
60	212.37	4.20×10^{-2}	0.9862	192.24	208.33	3.14×10^{-4}	0.9970

Table 3
A comparison between pseudo-first-order and pseudo-second-order kinetic models for Pb(II) uptake in continuous setup by immobilized dead *Pleurotus sajor-caju* biomass.

	Pseudo-first-order kinetic model			Experimental value	Pseudo-second-order kinetic model		
Metal	(mg/g)	q_e $K_{1,ads}$ (min^{-1})	R^2	q_e (mg/g)	q_e (mg/g)	$K_{2,ads}$ (g/mg min)	R^2
Pb(II)	205.39	3.70×10^{-2}	0.970	178.9	200	2.41×10^{-4}	0.9951

suggested the fitting of pseudo-second-order kinetic model (Tables 2 and 3) to remediation data of Pb(II).

3.7. Thermodynamics of biosorption process

Metal uptake process by biomass requires a thermodynamic approach to have complete understanding of the process. Thermodynamics applies only to equilibrium adsorption isotherms which was also a case in the present study. The separation factor (R_L), surface coverage (θ), free energy of adsorption ($\Delta G^\circ{}_{ads}$), enthalpy (ΔH°), and entropy (ΔS°) for adsorption of metal ions by biomass provide an accurate basis for predicting the thermodynamic properties and phase equilibria for adsorption from wastewaters. The details and equation for calculation of R_L, θ, $\Delta G^\circ{}_{ads}$, ΔH°, and ΔS° can be found in one of our previous works [32]. The values of R_L and $\Delta G^\circ{}_{ads}$ clearly show that Pb(II) adsorption uptake by immobilized *Pleurotus sajor-caju* biomass at lower concentrations (below 100 mg/L) was highly favorable at which even many modern methods (ion exchange, ultrafiltration, etc.) do not remain viable (Table 4). Metal uptake process by immobilized *Pleurotus sajor-caju* biomass was more spontaneous at lower concentrations. Surface coverage (θ) values give an idea about the biomass surface covered by metal ions. Surface coverage values increased from

Table 4
Calculated separation factor (E_p), surface coverage value (θ), and free energy ($\Delta G^\circ{}_{ads}$) profile for Pb(II) by immobilized dead *Pleurotus sajor-caju* biomass

Pb(II) Concentration (mg/L)	R_L	θ	$\Delta G^\circ{}_{ads}$
25	0.149872	0.850128	−1.51467
50	0.080489	0.919511	−0.45325
100	0.041513	0.958487	−0.12302
150	0.028948	0.971052	−0.06020
200	0.021665	0.978335	−0.03385
400	0.010999	0.989199	−0.00861
800	0.005476	0.994524	−0.00218
1,000	0.004393	0.995607	−0.00140

0.850128 to 0.995607 on increasing concentration from 25 to 1,000 mg/L. This suggests the saturation of available binding sites on biomass surface at higher metal ion concentrations. Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass was highly spontaneous and exothermic in nature as presented by entropy and enthalpy values (Table 5).

3.8. Effect of co-metal ions

The competitive adsorption of various metals in wastewater affects the biosorption behavior of metal of interest. The effect of various co-metal ions including Na(I), Ca(II), Cu(II), Al(III), Cr(III), and Cr(IV) on uptake of Pb(II) by immobilized *Pleurotus sajor-caju* biomass is presented in Fig. 4(a)–(f). The competitive biosorption of Pb(II) immobilized *Pleurotus sajor-caju* biomass was studied by fixing Pb(II) concentration at 100 mg/L while varying the concentration of Na(I), Ca (II), Cu(II), Al(III), Cr(III), and Cr(IV) from 0 to 400 mg/L. There was a reduction in Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass on increasing the concentration of competitive metal ion in aqueous solution. This may be due to a competition between the metal of interest and competitive metal ion/s for occupying fixed number of binding site present on biomass surface [34].

3.9. Column study

It was inferred from the obtained results of column study that Pb(II) uptake was higher in batch setup than continuous setup (Fig. 5(a)). Mungasavalli et al. [35] studied removal of chromium from aqueous solution using *Aspergillus niger* in batch and continuous mode. They have found that the removal of chromium was more in batch mode. A comparison between pseudo-first-order and pseudo-second-order kinetic models is tabulated in Table 3. A careful examination of the obtained parameters such as high value of correlation coefficient (R^2) and a close agreement between estimated and experimental q values suggested the fitting of pseudo-second-order kinetic model to Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass in continuous setup [8–38].

3.10. Desorption

To effectively conclude metal biosorption studies, it is necessary to carry out effective regeneration or desorption studies of biomass under investigation [39]. Desorbing agents used in the present study were EDTA, hydrochloric acid, sulfuric acid, nitric acid, and sodium hydroxide (Fig. 5(b)). The effectiveness of various desorbing agents was in following order:

Table 5
Pb(II) calculated enthalpy (ΔH°) and entropy (ΔS°) values for metal adsorption by white rot fungi

Immobilized Fungus	Metal	ΔH° (kJmol^1)	ΔS° (Jmol^{-1} K^{-1})
Pleurotus sajor-caju	Pb(II)	9.61	74.01

Table 6
A comparison between immobilized *Pleurotus sajor-caju* and previously used biosorbent for the uptake of Pb(II)

Biosorbent	Uptake capacity (mg/g)	Reference
Immobilized *Pleurotus sajor-caju*	227.08	The Present study
Immobilized *Rosa gruss an teplitz*	98.67	[27]
Immobilized *Rosa centifolia*	97.39	
Ceratophyllum demersum	44.80	[41]
Myriophyllum spicatum	46.49	[42]
Aspergillus flavus	10.82	[43]
Waste Chinese herb Pang Da Hai	27.10	[44]
Bacillus sp.	92.27	[45]
Chlamydomonas reinhardtii	96.30	[46]
Brown seaweed *Cystoseira baccata*	186.0	[47]

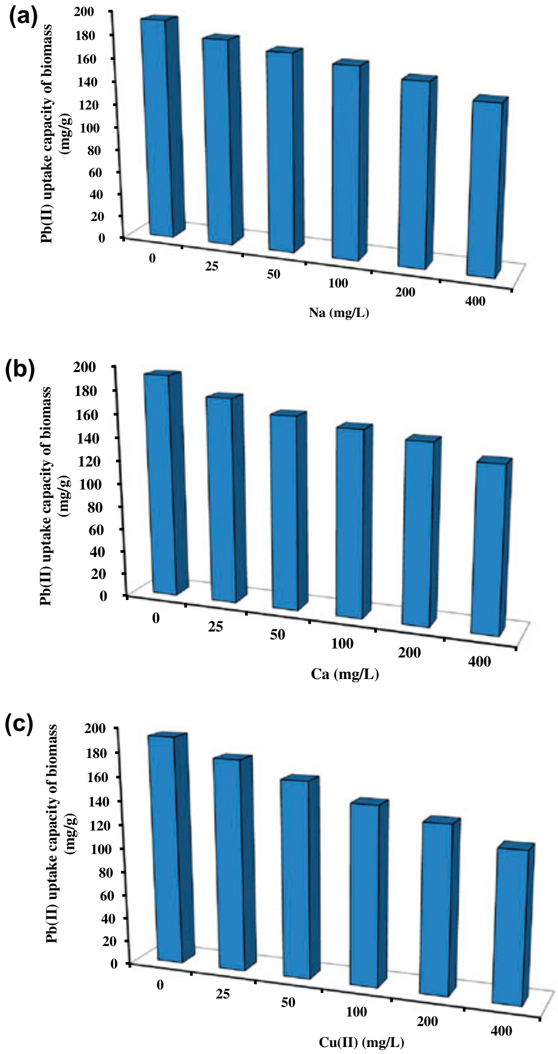

Fig. 4. Effect of various competing metal ions on uptake of Pb(II) by immobilized *Pleurotus sajor-caju* dead cells. (a) Na (I); (b) Ca (II); (c) Cu (II); (d) Al (III); (e) Cr (III); and (f) Cr (VI).

Sulfuric acid > EDTA > Hydrochloric acid > Acetic acid > Sodium hydroxide.

3.11. Industrial effluent

Real hazardous streams collected from the textile industry were subjected to biosorption studies in continuous setup for the removal of Pb(II) using immobilized *Pleurotus sajor-caju* biomass (Fig. 5(c)). Wastewater from industrial processes is generated in large volumes and it is preferable to treat them in continuous setup. The metal uptake was very rapid up to first 60 min followed by a slow increase up to 120 min of contact. The sorption equilibrium for Pb(II) uptake

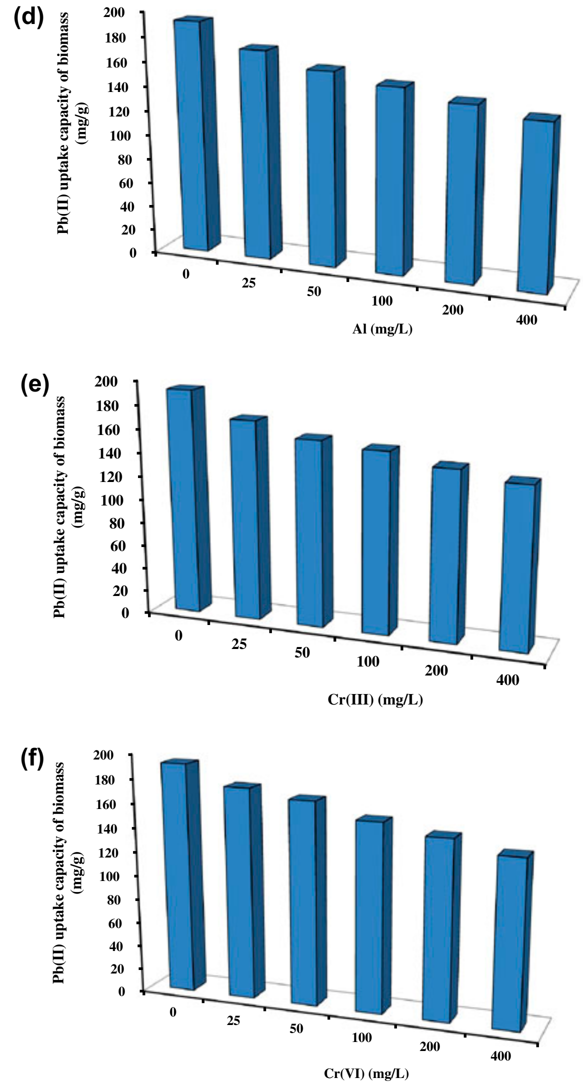

Fig. 4. (*Continued*).

by immobilized *Pleurotus sajor-caju* biomass was reached after 120 min. The Pb(II) removal by immobilized *Pleurotus sajor-caju* biomass from industrial wastewater was comparatively lower in comparison to aqueous solutions. This may be due to large number of competing ions present in case of real hazardous aqueous streams [40].

3.12. Pb(II) uptake capacity comparison

A comparison between Pb(II) uptake capacity of immobilized *Pleurotus sajor-caju* biomass with some previously used biosorbents is tabulated in Table 6 [41–47]. From Table 6, it can be concluded that immobilized *Pleurotus sajor-caju* biomass has more sorption capacity in comparison to earlier reported biosorbents.

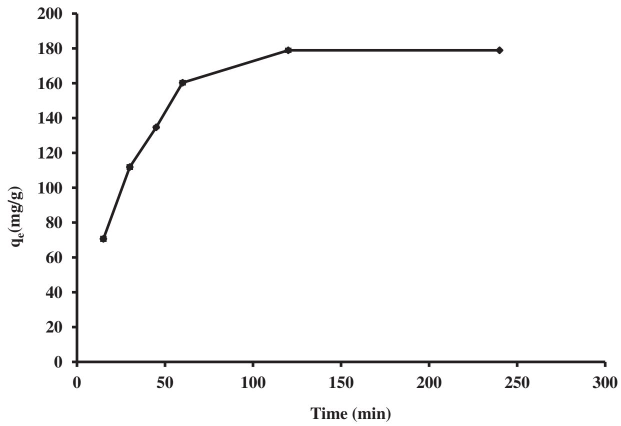

Fig. 5(a). Effect of contact time on uptake of Pb(II) by immobilized *Pleurotus sajor-caju* dead cells in continuous setup.

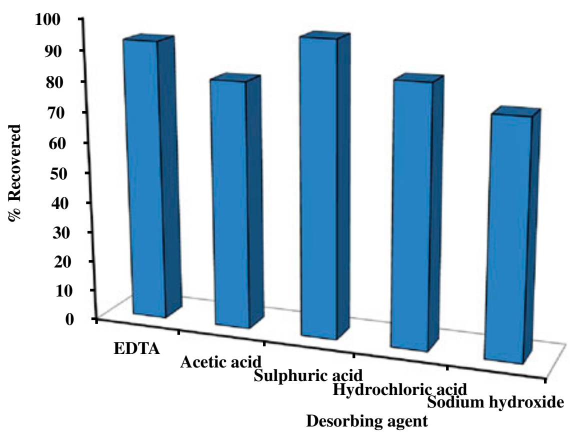

Fig. 5(b). Effect of various desorbing agents on recovery of Pb(II) ions adsorbed onto immobilized *Pleurotus sajor-caju* dead cells.

4. Conclusions

The search for ideal biomaterials for Pb(II) has been an active field of research in area of biosorption, biofiltration, bioremediation, bioaccumulation, phytoremediation, phytostabilization, etc. The present study reports the uptake of Pb(II) using immobilized *Pleurotus sajor-caju* biomass which proved to be an efficient biosorbent even at concentrations lower than 100 mg/L. The optimized pH, biomass dose, and contact time for Pb(II) uptake by immobilized *Pleurotus sajor-caju* biomass were 4.5, 0.50 g/L, and 120 min, respectively. The Pb(II) adsorption by immobilized *Pleurotus sajor-caju* biomass followed Langmuir adsorption isotherm and pseudo-second-order kinetic model. The calculated thermodynamic

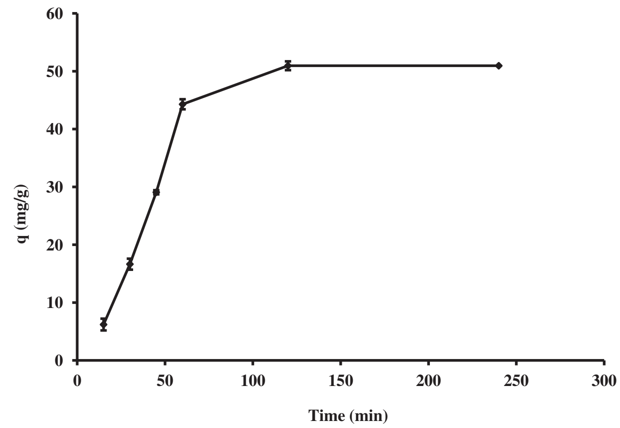

Fig. 5(c). Uptake of Pb(II) by immobilized *Pleurotus sajor-caju* dead cells from real hazardous industrial wastewater.

parameters suggest the suitability of immobilized *Pleurotus sajor-caju* biomass to adsorb Pb(II) even at concentrations lower than 100 mg/L.

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References

[1] J. Wang, C. Chen, Biosorption of heavy metals by Saccharomyces cerevisiae: A review, Biotechnol. Adv. 24(5) (2006) 427–451.

[2] S. Zafar, F. Aqil, I. Ahmad, Metal tolerance and biosorption potential of filamentous fungi isolated from metal contaminated agricultural soil, Bioresour. Technol. 98(13) (2007) 2557–2561.

[3] E.G. Pacyna, J.M. Pacyna, J. Fudala, E. Strzelecka-Jastrzab, S. Hlawiczka, D. Panasiuk, S. Nitter, T. Pregger, H. Pfeiffer, R. Friedrich, Current and future emissions of selected heavy metals to the atmosphere from anthropogenic sources in Europe, Atmos. Environ. 41(38) (2007) 8557–8566.

[4] N. Pirrone, P. Costa, J.M. Pacyna, Past, current and projected atmospheric emissions of trace elements in the Mediterranean region, Water Sci. Technol. 39(12) (1999) 1–7.

[5] A. Majeed, M.I. Jilani, R. Nadeem, M.A. Hanif, T.M. Ansari, Novel studies for the development of hybrid biosorbent, Int. J. Chem. Biochem. Sci. 2(1) (2012) 78–82.

[6] M. Kashefi, Salaryan Peyman, N. Hazeri, J. Valizadeh, A. Abdi, M.S. Mohammadnia, Biosorption of Cr(VI) from aqueous solutions using *Carum copticum* stem, Int. J. Chem. Biochem. Sci. 1(1) (2012) 48–53.

[7] M.A. Hanif, H.N. Bhatti, Bioremediation of nickel from wastewater using immobilized *Phanerochaete chyrsosporium* biomass, Int. J. Chem. Biochem. Sci. 2(1) (2012) 54–59.

[8] M.A. Hanif, H.N. Bhatti, Use of immobilized *Ganoderma lucidum* living cells for uptake of Ni(II) from wastewater, Int. J. Chem. Biochem. Sci. 4(1) (2013) 89–95.
[9] M. Alam, R. Nadeem, M.I. Jilani, Pb(II) removal from wastewater using Pomegranate waste biomass, Int. J. Chem. Biochem. Sci. 1(1) (2012) 24–29.
[10] K. Ahmad, I.A. Bhatti, M. Muneer, M. Iqbal, Z. Iqbal, Removal of heavy metals (Zn, Cr, Pb, Cd, Cu and Fe) in aqueous media by calcium carbonate as an adsorbent, Int. J. Chem. Biochem. Sci. 2(1) (2012) 48–53.
[11] H.M. Adeel, B. Parveen, N. Rasool, M. Riaz, K.G. Ali, Y. Gull, M. Noreen, M. Asghar, Biosorption of copper (II) from aqueous solution by *Ocimum bacilicum* seeds biomass, Int. J. Chem. Biochem. Sci. 4(1) (2013) 38–45.
[12] Y. Long, D. Lei, J. Ni, Z. Ren, C. Chen, H. Xu, Packed bed column studies on lead(II) removal from industrial wastewater by modified *Agaricus bisporus*, Bioresour. Technol. 152 (2014) 457–463.
[13] J. Bierkens, J. Buekers, M. Van Holderbeke, R. Torfs, Health impact assessment and monetary valuation of IQ loss in pre-school children due to lead exposure through locally produced food, Sci. Total Environ. 414 (2012) 90–97.
[14] K. Chatham-Stephens, J. Caravanos, B. Ericson, P. Landrigan, R. Fuller, The pediatric burden of disease from lead exposure at toxic waste sites in low and middle income countries, Environ. Res. 132 (2014) 379–383.
[15] S. Sathyanarayana, N. Beaudet, K. Omri, C. Karr, Predicting children's blood lead levels from exposure to school drinking water in seattle, Washington, USA, Ambul. Pediatr. 6(5) (2006) 288–292.
[16] F. Caurant, A. Aubail, V. Lahaye, O. Van Canneyt, E. Rogan, A. López, M. Addink, C. Churlaud, M. Robert, P. Bustamante, Lead contamination of small cetaceans in European waters—The use of stable isotopes for identifying the sources of lead exposure, Mar. Environ. Res. 62(2) (2006) 131–148.
[17] J. Richmond-Bryant, Q. Meng, J.A. Davis, J. Cohen, D. Svendsgaard, J.S. Brown, L. Tuttle, H. Hubbard, J. Rice, E. Kirrane, L. Vinikoor-Imler, D. Kotchmar, E. Hines, M. Ross, A multi-level model of blood lead as a function of air lead, Sci. Total Environ. 461–462 (2013) 207–213.
[18] R.E. Green, D.J. Pain, Potential health risks to adults and children in the UK from exposure to dietary lead in gamebirds shot with lead ammunition, Food Chem. Toxicol. 50(11) (2012) 4180–4190.
[19] M. Pizzol, M. Thomsen, M.S. Andersen, Long-term human exposure to lead from different media and intake pathways, Sci. Total Environ. 408(22) (2010) 5478–5488.
[20] P. Xiangliang, W. Jianlong, Z. Daoyong, Biosorption of Pb(II) by *Pleurotus ostreatus* immobilized in calcium alginate gel, Process Biochem. 40(8) (2005) 2799–2803.
[21] X. Wang, L. Chen, S. Xia, J. Zhao, J.-M. Chovelon, N.J. Renault, Biosorption of Cu(II) and Pb(II) from aqueous solutions by dried activated sludge, Miner. Eng. 19(9) (2006) 968–971.
[22] A. Sarı, M. Tuzen, Biosorption of Pb(II) and Cd(II) from aqueous solution using green alga (*Ulva lactuca*) biomass, J. Hazard. Mater. 152(1) (2008) 302–308.
[23] M. Riaz, R. Nadeem, M.A. Hanif, T.M. Ansari, K.U. Rehman, Pb(II) biosorption from hazardous aqueous streams using *Gossypium hirsutum* (Cotton) waste biomass, J. Hazard. Mater. 161(1) (2009) 88–94.
[24] M.H. Nasir, R. Nadeem, K. Akhtar, M.A. Hanif, A.M. Khalid, Efficacy of modified distillation sludge of rose (*Rosa centifolia*) petals for lead(II) and zinc(II) removal from aqueous solutions, J. Hazard. Mater. 147(3) (2007) 1006–1014.
[25] R. Nadeem, M.A. Hanif, F. Shaheen, S. Perveen, M.N. Zafar, T. Iqbal, Physical and chemical modification of distillery sludge for Pb(II) biosorption, J. Hazard. Mater. 150(2) (2008) 335–342.
[26] H.N. Bhatti, A. Saleem, M.A. Hanif, Utilization of *Mentha arvensis* waste biomass for the removal of Pb (II) and Co(II) from aqueous solutions, Desalin. Water. Treat. 51(16–18) (2013) 3335–3343.
[27] T.M. Ansari, M.A. Hanif, A. Mahmood, U. Ijaz, M.A. Khan, R. Nadeem, M. Ali, Immobilization of rose waste biomass for uptake of Pb(II) from aqueous solutions, Biotechnol. Res. Int. 2011 (2011) 1–9.
[28] N. Sankararamakrishnan, A.K. Sharma, R. Sanghi, Novel chitosan derivative for the removal of cadmium in the presence of cyanide from electroplating wastewater, J. Hazard. Mater. 148(1–2) (2007) 353–359.
[29] V. Prigione, G.C. Varese, L. Casieri, V.F. Marchisio, Biosorption of simulated dyed effluents by inactivated fungal biomasses, Bioresour. Technol. 99(9) (2008) 3559–3567.
[30] S.S. Ahluwalia, D. Goyal, Microbial and plant derived biomass for removal of heavy metals from wastewater, Bioresour. Technol. 98(12) (2007) 2243–2257.
[31] M.A. Hanif, H.N. Bhatti, M.A. Ali, Heavy metal uptake potential of various types of white rot fungi: A preliminary study and investigation of metal toxicity, J. Biotechnol. 136 (2008) S30.
[32] M.A. Hanif, R. Nadeem, H.N. Bhatti, N.R. Ahmad, T.M. Ansari, Ni(II) biosorption by *Cassia fistula* (Golden Shower) biomass, J. Hazard. Mater. 139(2) (2007) 345–355.
[33] O.D. Uluozlu, A. Sari, M. Tuzen, M. Soylak, Biosorption of Pb(II) and Cr(III) from aqueous solution by lichen (Parmelina tiliaceae) biomass, Bioresour. Technol. 99(8) (2008) 2972–2980.
[34] K. Chandrasekhar, C.T. Kamala, N.S. Chary, A.R. Sastry, T. Nageswara Rao, M. Vairamani, Removal of lead from aqueous solutions using an immobilized biomaterial derived from a plant biomass, J. Hazard. Mater. 108(1–2) (2004) 111–117.
[35] D.P. Mungasavalli, T. Viraraghavan, Y.-C. Jin, Biosorption of chromium from aqueous solutions by pretreated *Aspergillus niger*: Batch and column studies, Colloids Surf., A 301(1–3) (2007) 214–223.
[36] A. Hanif, H.N. Bhatti, M.A. Hanif, Removal of zirconium from aqueous solution by *Ganoderma lucidum*: Biosorption and bioremediation studies, Desalin. Water Treat. 2013 (2013) 1–11.
[37] S. Noreen, H.N. Bhatti, S. Nausheen, S. Sadaf, M. Ashfaq, Batch and fixed bed adsorption study for the removal of Drimarine Black CL-B dye from aqueous solution using a lignocellulosic waste: A cost affective adsorbent, Ind. Crops Prod. 50 (2013) 568–579.
[38] A. Kausar, H.N. Bhatti, G. MacKinnon, Equilibrium, kinetic and thermodynamic studies on the removal of U(VI) by low cost agricultural waste, Colloids Surf., B 111(3) (2013) 124–133.

[39] H.N. Bhatti, S. Hamid, Removal of uranium(VI) from aqueous solutions using Eucalyptus citriodora distillation sludge, Int. J. Environ. Sci. Technol. 11(3) (2013) 813–822.
[40] M.A. Hanif, R. Nadeem, M.N. Zafar, K. Akhtar, H.N. Bhatti, Kinetic studies for Ni(II) biosorption from industrial wastewater by *Cassia fistula* (Golden Shower) biomass, J. Hazard. Mater. 145(3) (2007) 501–505.
[41] O. Keskinkan, M.Z. Goksu, M. Basibuyuk, C.F. Forster, Heavy metal adsorption properties of a submerged aquatic plant (*Ceratophyllum demersum*), Bioresour. Technol. 92(2) (2004) 197–200.
[42] O. Keskinkan, M.Z.L. Goksu, A. Yuceer, M. Basibuyuk, C.F. Forster, Heavy metal adsorption characteristics of a submerged aquatic plant (*Myriophyllum spicatum*), Process Biochem. 39(2) (2003) 179–183.
[43] T. Akar, S. Tunali, Biosorption characteristics of *Aspergillus flavus* biomass for removal of Pb(II) and Cu(II) ions from an aqueous solution, Bioresour. Technol. 97 (15) (2006) 1780–1787.
[44] Y. Liu, X. Chang, Y. Guo, S. Meng, Biosorption and preconcentration of lead and cadmium on waste Chinese herb Pang Da Hai, J. Hazard. Mater. 135(1–3) (2006) 389–394.
[45] S. Tunali, A. Çabuk, T. Akar, Removal of lead and copper ions from aqueous solutions by bacterial strain isolated from soil, Chem. Eng. J. 115(3) (2006) 203–211.
[46] İ. Tüzün, G. Bayramoğlu, E. Yalçın, G. Başaran, G. Çelik, M.Y. Arıca, Equilibrium and kinetic studies on biosorption of Hg(II), Cd(II) and Pb(II) ions onto microalgae *Chlamydomonas reinhardtii*, J. Environ. Manage. 77(2) (2005) 85–92.
[47] P. Lodeiro, J.L. Barriada, R. Herrero, M.E. Sastre de Vicente, The marine macroalga *Cystoseira baccata* as biosorbent for cadmium(II) and lead(II) removal: Kinetic and equilibrium studies, Environ. Pollut. 142 (2) (2006) 264–273.