

Full Length Research Paper

Biosorption of lanthanum from aqueous solution using *Pleurotus ostreatus* basidiocarps

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The biosorption of lanthanum by *Pleurotus ostreatus* biomass is determined at varying experimental conditions using a batch technique. The effects of pretreatment, initial metal ion concentration, initial pH, biosorbent dosage, contact time and temperature have been investigated. The optimum biosorption conditions for biosorption are as follows: 150 mg/L of La^{3+} as initial concentration, 500 mg/L (dry wt. cell) biomass for biosorption, pH 6.8, temperature 40°C, biosorption time 10 min and mixing speed 175 rpm. The Langmuir and Freundlich isotherms are applied to represent the biosorption process. Langmuir isotherm fits the experimental data quite well. The Langmuir monolayer capacity of the sorbent is 54.54 mg/g. Thermodynamic parameters such as standard enthalpy (ΔH°), entropy (ΔS°) and free energy (ΔG°) are calculated from the slope and intercept of the plots of $\ln K_d$ versus $1/T$. The results indicated that sorption is endothermic and spontaneous in nature. SEM and IR analyses are used for characterization of the biosorbent agent after and before the biosorption process. The work reveals that *P. ostreatus* biomass is a good choice as a biosorbent for the recovery of lanthanum from aqueous solution.

Key words: Biosorption, lanthanum, thermodynamic, *Pleurotus ostreatus*.

INTRODUCTION

Rare earth elements (REEs) have gained considerable attention owing to their unique properties and a wide range of applications. Among REE, La^{3+} is one of the most abundant and reactive elements. Lanthanum is one of the light rare earth elements which are used in many industries such as semi-conductor, flint, battery electrodes, fluid catalytic cracking and super alloys (Palmieri et al., 2002). Conventional methods for removing metals from aqueous solutions include chemical precipitation, evaporation, ion exchange, membrane filtration and reverse osmosis. These processes may be ineffective or extremely expensive (Gabr et al., 2008). The development of technically simple, low cost operating, minimized temperature and energy demand, feasible biomass regeneration and ecofriendly method for removal of the desired metals from bearing solution is one of the most important priorities of the 21st century (Paul et al., 2006).

Biosorption can be defined as the removal of metal or metalloid species, compounds and particulates from solution by non-living biological material (Davis et al., 2003). The process is a rapid, reversible, economical and

ecofriendly technology in comparison with conventional chemical methods (Ahuja et al., 1999). Mushroom of *Pleurotus ostreatus* grows on wood on nature, usually on dead standing trees or fallen logs. It has a relatively large size, whitish gills and exceptionally small stem. It fruits in fall and winter and has a brownish cap (Danis et al., 2012). In the present experiment, the biosorption behaviors of La^{3+} ions on *P. ostreatus* are investigated with various chemical methods and Fourier transformer infrared (FTIR) spectrometry. Parameters studied include the effects of solution pH, contact time, biosorbent dosage, initial ion concentration and temperature by batch method. Furthermore, the Langmuir and Freundlich biosorption isotherms and thermodynamic parameters are applied.

MATERIALS AND METHODS

Microorganism and biomass preparation

P. ostreatus on millet grains were obtained from Mushroom Cultivation Farm from the Faculty of

Agriculture, Mansoura University. A mixture of known amount of rice straw, wheat brain (5%) and CaCO_3 (5%) in bags were soaked in hot tap water for 3 h for pasteurization. The *P. ostreatus* on millet grains have were inoculated in the sterile substrate in a multilayered form. The spawned bags were placed in dark at $20 \pm 3^\circ\text{C}$ for three weeks. The mature basidiocarps were collected and washed several times with distilled water then cut into small pieces. The air dried basidiocarps were ground in a mortar and sieved to select particles of less than 0.5 mm (mesh size 125-250 μm) for use as a biosorbent agent.

Biosorption experiments

Lanthanum solution preparation and biosorbent agent pretreatments

Lanthanum stock solution (1g/L) is prepared separately from $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ obtained from Alfa Aesar. The working solutions are prepared by diluting the stock solution to appropriate volume. The pretreatments of the biomass are achieved by alkaline, acidic and heat drying as previously described by Shuxia et al. (2011).

Factors affecting the biosorption process

The biosorption experiments were conducted with 50 mL of 50 mg/L initial concentration of La^{3+} ions solution in 250 mL Erlenmeyer flask for 60 min contact time at room temperature $26 \pm 1^\circ\text{C}$. Effect of initial REEs ion concentration on biosorption was studied between 50-350 mg/L. Effect of initial La^{3+} ions concentration on biosorption was studied between 50-350 mg/L. The amount of *P. ostreatus* biosorbent was administered between 50-600 mg. Effect of initial pH on biosorption was evaluated with values ranging from 2-8 using 0.1 mol/L NaOH or HCl. The contact time chosen for the time dependence studies were 10 to 60 min. The effect of temperature on biosorption was performed from 20 to 60°C .

Lanthanum measurement

The supernatants were filtered through a filter paper (Whatman No. 41) and the concentration of La^{3+} in the solution was measured before and after equilibrium by Metertech Ino model Sp-5001 (UV- Visible spectrophotometer) using arsenazol (Marczenko, 1976).

The amount of metal biosorbed by *P. ostreatus* was calculated using the following equation:

$$Q_e = (C_o - C_e) \times \frac{V}{M} \quad (1)$$

where Q_e is the metal uptake (mg/g), C_o and C_e are the initial and equilibrium metal concentrations in the solution (mg/L), respectively, V is the solution volume (L), and M is the mass of biosorbent (g):

$$\text{The percent of biosorption rate} = \frac{(C_o - C_e)}{C_o} \times 100 \quad (2)$$

The distribution coefficient (K_d) of metal ions between the aqueous phase and the solid phase can be directly obtained using:

$$K_d = \frac{(C_o - C_e)}{C_o} \times \frac{V}{M} \quad (\text{mL/g}) \quad (3)$$

where C_o (g/L) and C_e (g/L) are the initial and equilibrium lanthanum or cerium concentrations, respectively, V/M is the ratio of the volume of metal solution (mL) to the amount of biosorbent (g) in a batch.

SEM observation

The texture, pore structure and loaded biomass of *P. ostreatus* are observing under high resolution Environmental Scanning Electron Microscope (ESEM), Philips XL30 vacuum at 30 KV.

Infrared analysis

Infrared spectrophotometer was used to determine the functional groups presented on the surface of *P. ostreatus* biomass before and after loading with La^{3+} . The apparatus used (Model JASCO 4100 FTIR spectrophotometer, Japan) were presented in the Micro Analytical Center, Cairo University, Egypt. The samples were prepared as KBr discs.

Desorption study

Desorption experiments were performed by mixing *P. ostreatus* loaded biomass (500 mg dry weight) with desorbing agents 50 mL of (0.1, 0.2, 0.3 N HCl and 0.1, 0.2, 0.3 N HNO_3) for 1 h on a rotary shaker (175 rpm) at 30°C for three cycles to study the elution rate (Sert et al., 2008).

Statistical analysis

All obtained experimental results are subjected to statistical analysis using statistical software SPSS (Ver, 10) as described by Steel et al. (1997).

RESULTS

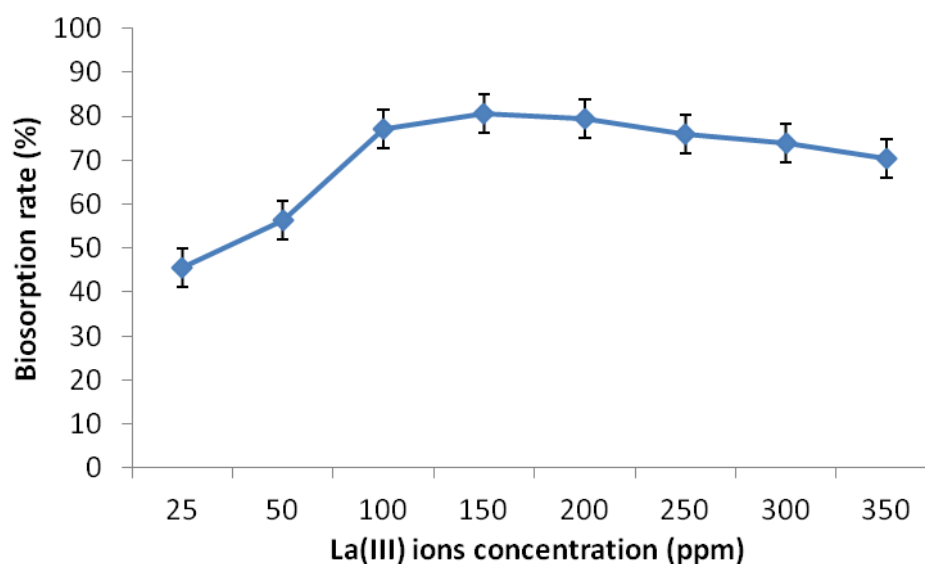
Effect of different pretreatments on the biosorption of La^{3+} by *P. ostreatus*

Table 1 shows that the biosorption rate of La^{3+} by *P. ostreatus* reduced as the concentration of NaOH and HCl increased. The obtained results appear that the pretreated biomass with 0.2 M NaOH solution has the maximum biosorption rate of 74.07% and the biosorption amount was 35.27 mg/g.

Table 1. Effect of different pretreatments on biosorption of La^{3+} ions by *P. ostreatus*.

Treatments	Concentration (mol/L)	Biosorption rate (%)	Biosorption amount (mg/g)
1- Control (dried at room temperature $30\pm 2^\circ\text{C}$)	-	68.81 ± 1.87	31.59 ± 1.99
	0.1	69.11 ± 3.99	30.73 ± 1.33
	0.2	74.07 ± 2.66	35.27 ± 2.77
2- Soaked with NaOH for 40 min	0.3	70.43 ± 1.45	32.45 ± 3.11
	0.1	56.39 ± 3.87	29.74 ± 2.13
	0.2	53.17 ± 3.89	27.59 ± 2.89
3- Soaked with HCl for 40 min	0.3	50.94 ± 3.59	25.99 ± 2.18
	-	66.57 ± 3.22	33.23 ± 3.90
4- Soaked with 30% ethyl alcohol for 40 min (Shuxia et al., 2011)	-	66.57 ± 3.22	33.23 ± 3.90
	-	66.57 ± 3.22	33.23 ± 3.90
5- Heat drying	at 60°C	54.73 ± 3.77	25.62 ± 1.89
	at 80°C	50.98 ± 2.98	23.54 ± 2.12

* Biosorption conditions: 50 mg/L La^{3+} , 150 mg/L dry wt. cell, pH 6.5, 30°C , 175 rpm and 2 h biosorption time.

**Figure 1.** Effect of initial concentrations of La^{3+} ions on the biosorption by *P. ostreatus*.

Effect of initial La^{3+} ions concentration

The effect of initial metal concentration on the biosorption rate by *P. ostreatus* is illustrated in Figure 1. The biosorption percentage of La^{3+} ions shows a decreasing trend as metal ions concentration increase. The maximum removal of La^{3+} ions is 80.84% at La^{3+} ions concentration (150 mg/L).

Effect of initial pH

The percentage of La^{3+} ions removal is strongly dependent on pH as shown in Figure 2. The pH seems to

be the most important parameter in the biosorptive process. It affects the metal ions chemical property, competition, the activity of its combining site, that is, the functional group of a microorganism. It has been found that the maximum removal of La^{3+} ions was found to be 82.56% at pH 6.8.

Effect of biomass concentration

Effect of biomass concentration on the biosorption of La^{3+} ions by *P. ostreatus* is presented in Figure 3. With an increase in biomass concentrations from 50 to 600 mg, the percentage of La^{3+} ions removal increase from 30.45

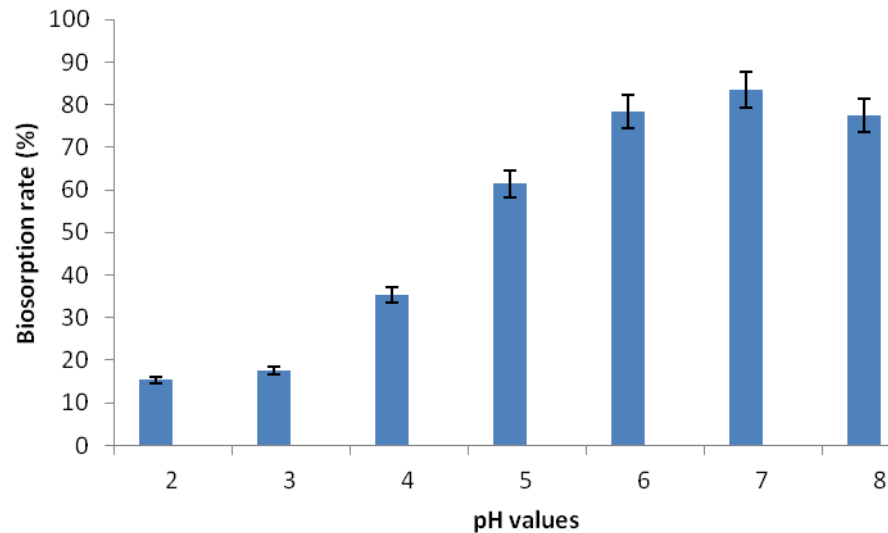


Figure 2. Effect of different pH on the biosorption La^{3+} ions by *P. ostreatus*.

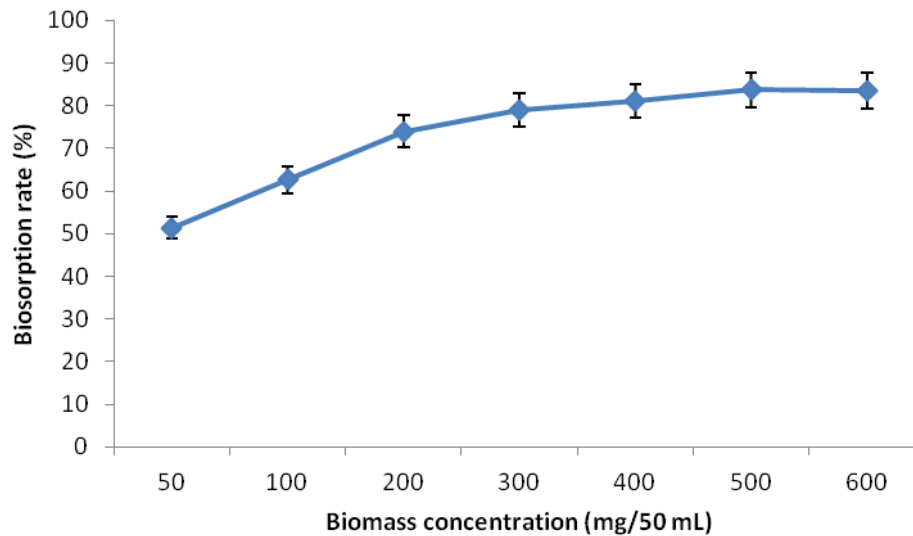


Figure 3. Effect of biomass concentrations of *P. ostreatus* on the biosorption of La^{3+} ions.

to 83.45%. The percentage of La^{3+} ions removal reaches equilibrium at 500 mg biomass concentration.

Effect of contact time

Figure 4 shows La^{3+} ions removal, at different contact time by *P. ostreatus*. It is observed that there are two stages for the removal of La^{3+} ions, an initial rapid increase in removal percentage during the first 20 min and then followed by a plateau phase at 88.99% for La^{3+} ions.

The effect of temperature

The experiments were carried out at 20, 30, 40, 50 and 60°C. The other parameters were kept constant.

Lanthanum solution was shaken with 500 mg of *P. ostreatus* at pH 6.8 for 10 min. Figure 5 shows that with increasing temperature, there is a slightly increasing effect for La^{3+} ions. It was found that the temperature 40°C was considered the suitable degree for maximum biosorption rate of 92.99%.

In any biosorption procedure, both standard energy and entropy considerations should be taken into account in order to determine which process will take place spontaneously. Biosorption enthalpy is measured using the method based on the Van't Hoff plot. The values of ΔH° and ΔS° were calculated from the slopes and intercepts of the linear variation of $\ln K_d$ with reciprocal temperature, $1/T$ (Figure 6), using the relation.

The thermodynamic parameters, such as changes in the standard free energy (ΔG°), enthalpy (ΔH°) and

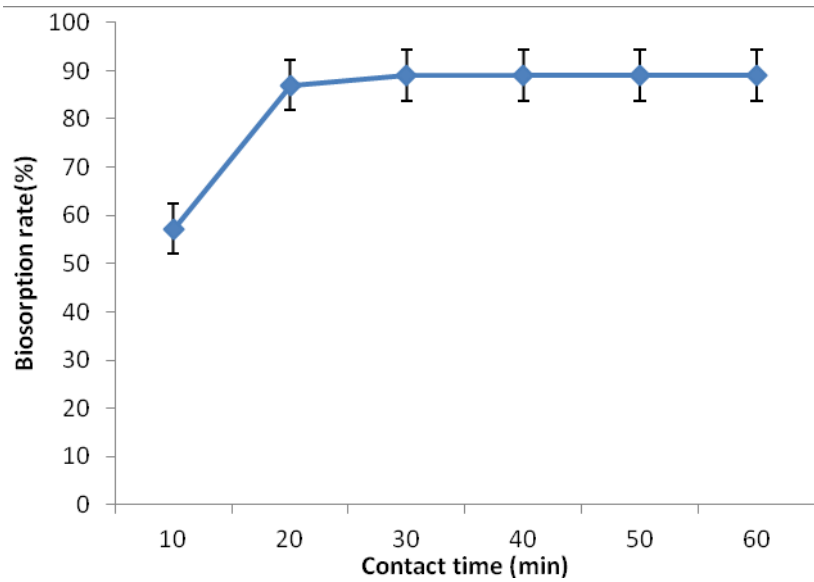


Figure 4. Effect of contact time on the biosorption La^{3+} by *P. ostreatus*.

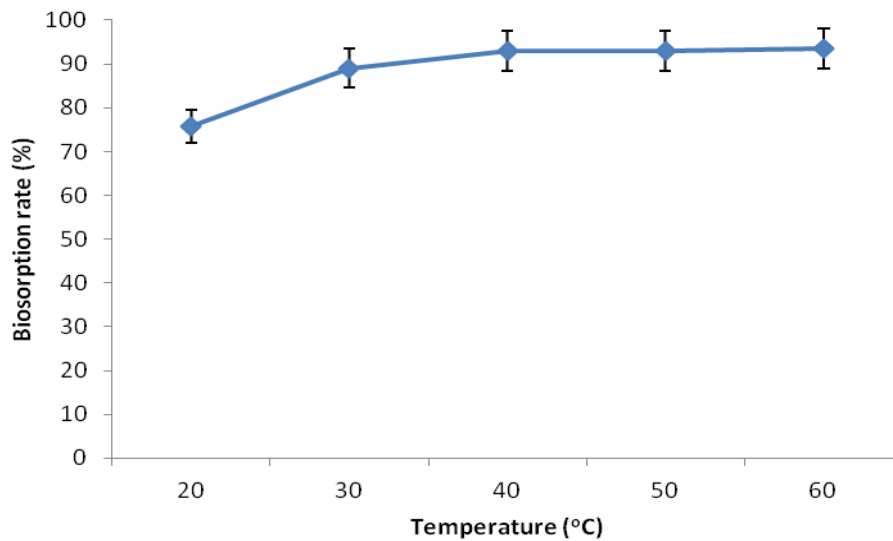


Figure 5. The effect of temperature on the biosorption of La^{3+} by *P. ostreatus*.

entropy (ΔS°) associated with the biosorption process are determined by using the following equations:

$$\text{Slope} = \frac{-\Delta H^\circ}{RT} \quad (4)$$

$$\Delta G^\circ = -RT \ln Kd \quad (5)$$

$$\ln Kd = -\frac{\Delta G^\circ}{RT} = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \quad (6)$$

where R is the gas constant and T is the absolute temperature as mentioned in Arrhenius equation. The

plot of $\ln Kd$ versus $1/T$ gives the straight line from which ΔH° and ΔS° is calculated from the slope and intercept of the linearised form of Figure 6 which shows in Table 2.

Characterization of the biosorbent agent by scanning electron microscope (SEM) and infrared analysis spectral analysis (IR)

SEM observation

Plate 1A shows the global intact fiber like structure of the air dried non-treated *P. ostreatus* biomass. Sodium hydroxide treated biomass examination appears in Plate 1B. The structure resembles a rigid particle composition. The porosity improves as the volatiles are released. The

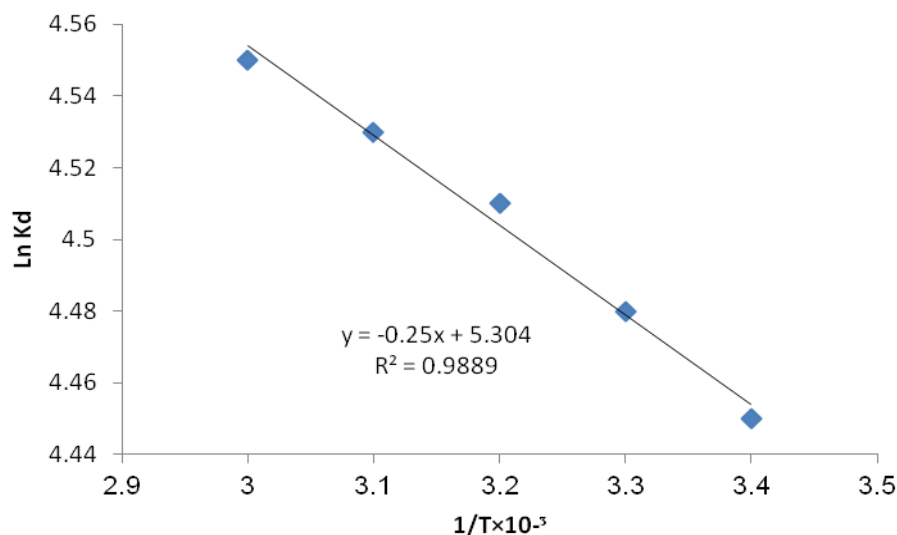


Figure 6. Plots of $\ln K_d$ versus $1/T$ for the lanthanum biosorption on *P. ostreatus*.

Table 2. Thermodynamic parameters for the biosorption of lanthanum by *P. ostreatus*.

Concentration ($\mu\text{g/mL}$)	ΔH° (kJ/mol)	ΔS° (J/K.mol)	ΔG° (kJ/mol)				
			293 K	303 K	313 K	323 K	333 K
150	6.65	39.49	-11.56	-12.00	-12.44	-12.75	-13.14

surface structure morphology may exhibit microstructure porosity. Also, Plate 1C appears that all microstructures porosities seem to be filled with La^{3+} ions.

IR spectral analysis

Changes in the functional groups and surface properties of the biosorbent are confirmed by FTIR spectra before and after La (III) biosorption. Figure 7 shows the FTIR spectra of *P. ostreatus* owning different functional groups before and after the biosorption. After biosorption of La^{3+} ions on *P. ostreatus*, a considerable shifting of peaks was observed from 400 to 4000 wavenumbers.

According to the FTIR spectra, it is thought that, there is a physical and chemical attraction between the La (III) ions and the functional sites on the *P. ostreatus* biomass. This interaction between the La (III) ions and the sites on *P. ostreatus* biomass modify the values of transmittance versus the wave number.

The functional groups on *P. ostreatus* having specific value of absorbance at different wave numbers are summarized in Table.3. The bonds at different wave numbers (3430.74, 2924.52, 2135.78, 1650.77, 1415.49, 1314.25 and 602.64 cm^{-1}) on *P. ostreatus* before biosorption have been detected as O-H, C-H, $\text{C}\equiv\text{C}$, C=O, C-H, C-N and C-X, respectively.

Biosorption isotherms

Langmuir isotherm

Experimental isotherm relates to the biosorption of La^{3+}

ions onto *P. ostreatus* test using Langmuir and Freundlich isotherms. Initially the Langmuir model was applied to the present system and the model is able to describe the isotherm data with high R^2 as shown in Table.4. The Langmuir biosorption isotherm has traditionally been used to quantify and contrast the performance of different sorbents. This model served to estimate the maximum metal uptake value (Q_{max}). The constant b represents affinity between the sorbent and the sorbate (Table 4).

The Langmuir equation, which was successfully applied to many biosorptions, is given thus:

$$\frac{C_e}{Q_e} = \frac{1}{b n m} + \frac{C_e}{n m} \quad (7)$$

where, C_e is the equilibrium concentration (mg/L), Q_e is the amount adsorbed at equilibrium (mg/g), $n m$ and b are the Langmuir constants related to monolayer capacity and energy of biosorption. Also, it can be evaluated from the intercept and slope of the linear plot of C_e/Q_e versus C_e Figure 8.

Freundlich isotherm

The Freundlich isotherm was originally empirical in nature but was later interpreted as sorption to heterogeneous surfaces or surfaces supporting sites of varied affinities. It is assumed that the stronger binding sites are occupied first and that binding strength decreases with the increasing degree of site occupation. Freundlich

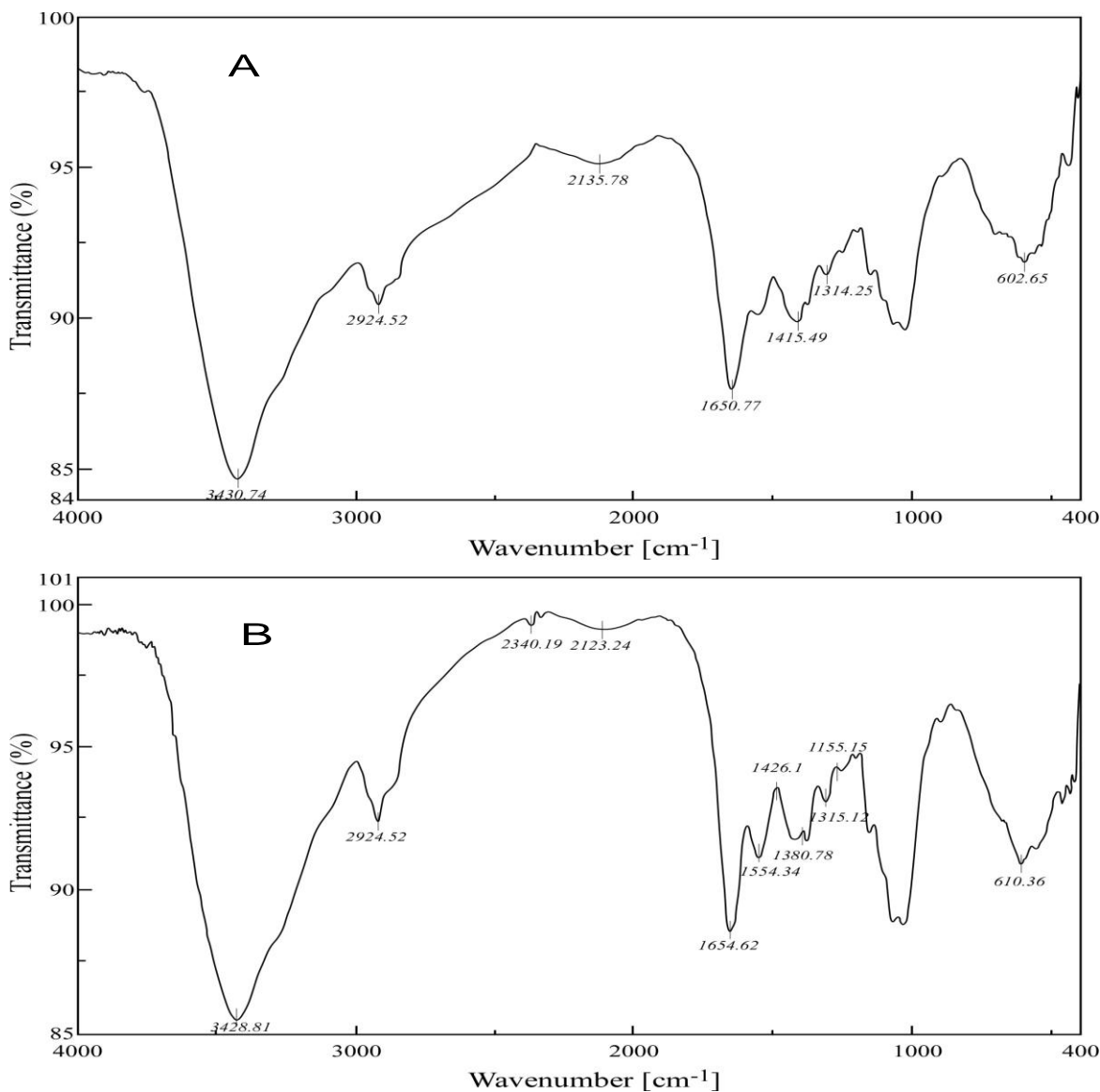


Figure 7. Infrared spectra of *P. ostreatus* biomass non-loaded (control) (A) and loaded (B) with La^{3+} ions.

equation, which is apply for the biosorption of La^{3+} ions, is given as:

$$\text{Log } q = \text{log } K + \frac{1}{n} \text{log } ce \quad (8)$$

where q is the amount of solute biosorbed per mass unit biosorbent, C_e is the equilibrium concentration, k and n are the Freundlich constants characteristic of a particular biosorption isotherm and can be evaluated from the intercept and slope of the linear plot of $\text{log } q$ versus $\text{log } C_e$ (Figure 9).

Desorption of lanthanum

Desorption studies are conducted immediately after the

biosorption of La^{3+} by *P. ostreatus*. Figure 10 indicated that using 0.1N HNO_3 for three washing cycles have been found to be the best eluting agent. The desorption percentage of La^{3+} ranged from 66.90 to 96.89%.

Removal of La^{3+} ions from rare earths concentrate solution

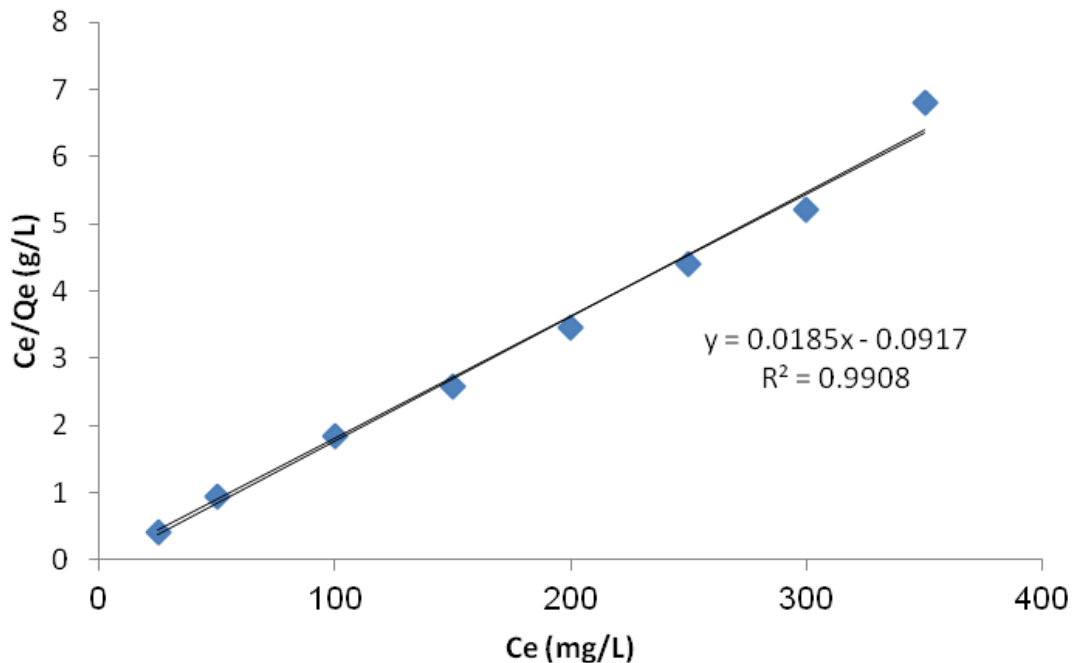
The chemical composition of rare earths concentrate solution obtained from Egyptian monazite was presented as 20.75% La_2O_3 , 34.71% Ce_2O_3 , 6.78% Pr_2O_3 , 14.98% Nd_2O_3 , 2.42% Sm_2O_3 , 2.69 % Gd_2O_3 , 1.11% Tb_2O_3 and 2.34% Y_2O_3 . In addition to P_2O_5 , Fe_2O_3 and loss of ignition (LOI) were presented in percentages 4.20%, 3.13% and 6.89%, respectively. Under the previously obtained optimum conditions for biosorption of La^{3+} ions, it was found that the percentage of removal from

Table 3. Functional groups of *P. ostreatus* biomass non-loaded and loaded with La^{3+} and the corresponding infrared absorption wave lengths.

Variable	Band	Type of compound	Frequency (cm^{-1})	Reference frequency range (cm^{-1})
Before Biosorption	O-H	Hydrogen bonded alcohols	3430.74	3200-3600
	C-H	Alkynes	2924.52	2850-2970
	$\text{C} \equiv \text{C}$	Terminal alkynes	2135.78	2100-2140
	C=O	Carboxylic acid	1650.77	1550-1820
	C-H	Alkyl methyl	1415.49	1340-1470
	C-N	Amines-amides	1314.25	1180-1360
	C-X	Chloroalkanes	602.65	540-760
After Biosorption	O-H	Hydrogen bonded alcohols	3428.81	3200-3600
	C-H	Alkynes	2924.52	2850-2970
	C-H	Alkyl methylene	2340.19	2134-2400
	$\text{C} \equiv \text{C}$	Terminal alkynes	2123.24	2100-2140
	C=O	Carboxylic acid	1654.62	1550-1820
	C=C	Aromatic rings	1554.34	1500-1600
	C-H	Alkyl methyl	1426.10	1340-1470
	C-H	Alkanes	1380.78	1340-1470
	C-N	Amines-amides	1315.21	1180-1360
	C-O	Tertiary Alcohols	1155.15	1150-1200
	C-X	Chloroalkanes	610.36	540-760

Table 4. Langmuir and Freundlich constants for the biosorption of La^{3+} ions on *P. ostreatus*.

Lanthanum	Langmuir constants			Freundlich constants		
	R^2	nm (mg/g)	b (L/mg)	R^2	N	K
	0.9908	54.54	0.19	0.8765	2.76	6.87

**Figure 8.** Langmuir plots for the biosorption of La^{3+} ions on *P. ostreatus*.

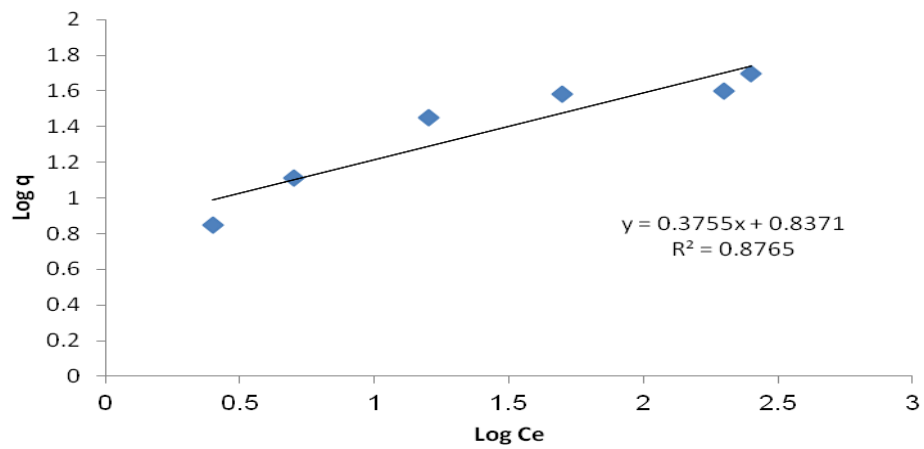


Figure 9. Freundlich plots for the biosorption of La^{3+} ions on *P. ostreatus*.

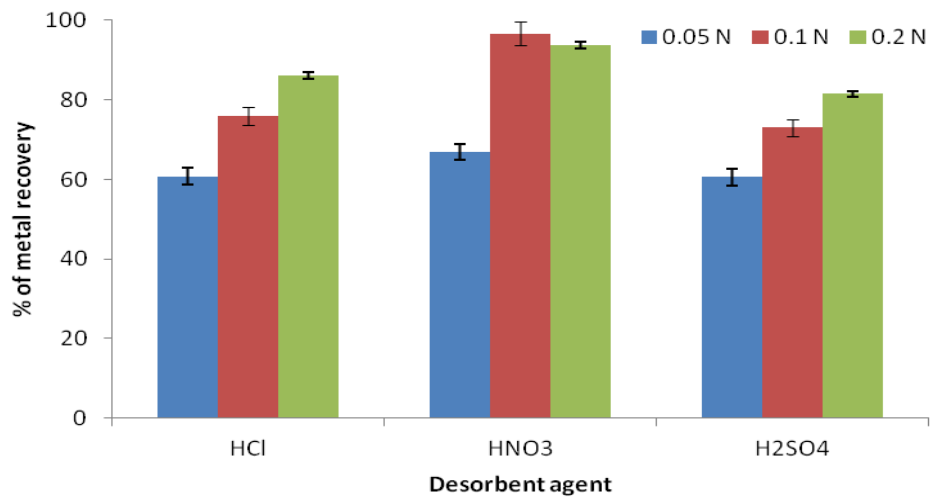


Figure 10. Desorption of La^{3+} ions by different desorbent agent.

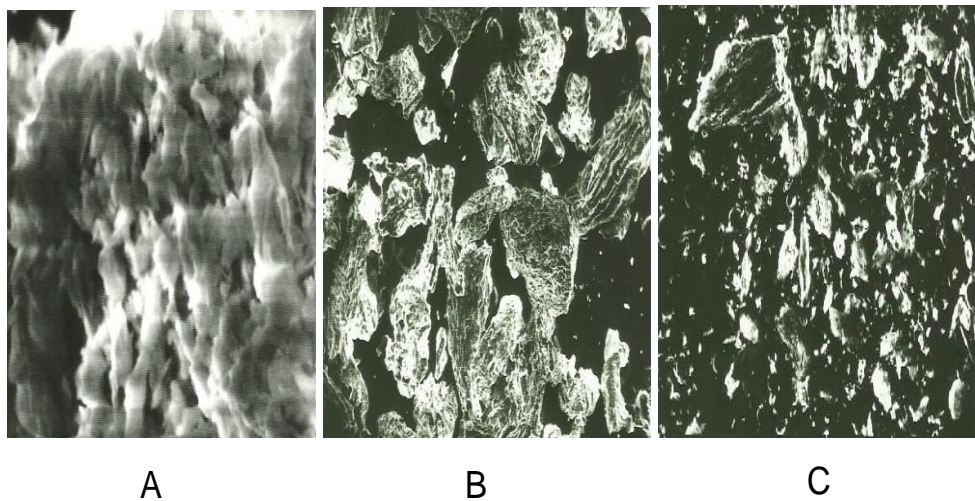


Plate 1. SEM photographs at 100X magnifications: (A) Dried *P. ostreatus* biomass, (B) Treated *P. ostreatus* biomass by NaOH and (C) La^{3+} ions loaded *P. ostreatus* biomass.

concentrate of REEs solution was to be 78%. In addition, 85% of biosorbed La^{3+} ions were desorbed by 0.1 N HNO_3 .

DISCUSSION

The comparison of La^{3+} ions biosorption rate with native and pretreated *P. ostreatus* appears that, 0.2 M NaOH have the maximum biosorption rate. The reason may be that alkali pretreatment could remove the amorphous polysaccharide on the cell wall and change the structure of the dextran and chitin, so the biomass could biosorb much more La^{3+} ions on its surface. At the same time, NaOH could dissolve the inclusions in the cell which encumber biosorption, and expose much more active binding sites to improve the biosorption capacity. Furthermore NaOH makes H^+ to be dissociated from the cell wall, resulting in the increase of negative functional groups, then the improvement of the biosorption capacity (Shuxia et al., 2011). The removal of La^{3+} ions decreased from 80.84 to 70.45% and with an increase of La^{3+} ions concentration from 150 to 350 mg/L. The maximum removal of La^{3+} ions was obtained at concentration of 150 mg/L. The increase of La^{3+} ions concentration may lead to the increase in the number of ions competing for the available binding sites in the biomass which result in the limitation of vacant binding sites, thus decreasing REEs ion removal yields. A similar interpretation can be made for La and Ce (III) biosorption on powdered leaf of *P. orientalis* observed by Sert et al. (2008). An important factor controlling the process of adsorption is pH, as it affects the surface charge of the biosorbent and the degree of ionization (López et al., 2000). pH 6.8 was considered the optimum value at which maximum removal of La^{3+} was 82.56%.

Generally, under the condition of low pH, the content of H^+ was more than others in the solution. Protons compete with La^{3+} ions for most of the binding sites on the biosorbent surface. Under the condition of high pH, more groups and more loci with negative charge will be exposed, so the La^{3+} ions with positive charge can be adequately attracted. On the contrary, under alkaline conditions, deprotonation of the heavy metals binding sites and precipitation of REEs ions as insoluble hydroxides or hydrated oxides is believed to be responsible for the decrease in REEs ions removal of *P. ostreatus*. Qing (2010) also reported that pH 7.0 was the maximum pH for removal of La^{3+} ions from aqueous solution by bamboo charcoal. Biomass concentration is a significant factor to have been considered for effective metal removal sorbent-sorbate equilibrium of the system (Danis et al., 2012). Dose of biomass added into the solution determined the number of binding sites available for biosorption. The maximum removal of La^{3+} ions (83.45%) was obtained at 500 mg biomass concentration. The increase in biomass concentration could be attributed to increase in surface area which led to interference between the binding sites and prevent the combination of metal ion with the corresponding sites (Pagnanelli et al., 2000). Other factors such as static

electricity interaction and the disturbance of active sites have an impact on the biosorption. Therefore the biosorption rate would decline with addition of too many cells (Shuxia et al., 2010). The maximum removal of La^{3+} ions (88.99%) was obtained after 20 min. This indicates that initially the presence of abundant vacant binding sites becomes saturated after these sites were occupied. The remaining vacant binding sites might also be difficult to occupy due to the repulsive force between the solute molecules of the solid and bulk phase.

Tay et al. (2010) have reported similar trend of observation where by the removal of Cd (II) by *P. ostreatus* biosorbent from industrial water reached equilibrium condition and there were no significant changes with further increase in contact time. It can be observed that when the temperature of the solution changes from 20 to 60°C, the biosorption rate increases. Similar observation was made by Meena et al. (2005) who reported that the increase in biosorption with temperature may be attributed to either an increase in the number of active surface sites available for biosorption on the biosorbent or the decrease in the thickness of the boundary layer surrounding the biosorbent with temperature, so that the mass transfer resistance of biosorbate in the boundary layer decreases. The negative values of ΔG° , -11.56, -12.00, -12.44, -12.75 and -13.14 kJ/mol, in the experimental temperatures range, confirmed the spontaneity of the biosorption process with increasing temperature, and the positive value of ΔH° (6.65 kJ/mol) indicate that the biosorption is spontaneous and endothermic in nature. In addition, the value of ΔS° (39.49 J/K.mol) was found to be positive due to the exchange of the metal ions with more mobile ions present on the exchanger, which would cause increase in the entropy, during the biosorption process. These obtained results are in agreement with those obtained by Qing (2010). SEM examination shows a rigid structure of pretreated biomass. The fact is that NaOH treatment removes most of the cell wall materials containing –COOH, phosphate groups and amorphous polysaccharides. Thus, it generates clean surface morphology and more accessible space within β -glucan-chitin skeleton, hence allowing more metals ions chelation at the surface (Amini et al., 2009). Also loaded biomass appears to be more filled with metal ions. This obtained result may be due to the biosorption affinity between the biomass and element (Carol et al., 2012). Using IR illustrates that after biosorption of La^{3+} ions on *P. ostreatus*, the values of transmittance and wave number of bonds on the *P. ostreatus* change and form new bonds. The new bands were formed at different wave numbers of 2340.19, 1554.34 and 1155.15 cm^{-1} for C-H, C=C and C-O, respectively. Danis et al. (2012) also observed a similar result on biosorption of Cu (II) by *P. ostreatus*. It is evident that the biosorption of La^{3+} ions onto *P. ostreatus* is fitted better to the Langmuir isotherm model than that of the Freundlich isotherm models, as indicated by the R_2 values and the biosorption capacity calculated from Langmuir isotherm equation which defines the maximum capacity of the biosorbent for La^{3+}

ions as 54.54 mg/g. Sert et al. (2008) reported that the biosorption capacity of *P. orientalis* leaf powder for lanthanum is 28.65 mg/g while the maximum biosorption capacity (Q_{max}) of *Sargassum fluitans* for lanthanum chloride is 101.4 mg/g at pH 5.0 as previously mentioned by Palmieri and Volesky (2002). Desorption/recovery of biosorbed metal is one of the most important aspects of any successful biosorption process development (Kazy et al., 2006). It shows that 0.1 N HNO_3 could be eluted by about 96.89% of La^{3+} ions. According to Diniz and Volesky (2006) in the batch desorption technique used, it is likely that at weak acidity, a new low-pH equilibrium is reached in the desorption system, preventing the complete elution and release of the sorbate metal into the solution. The percentage of desorption increased with acid concentrations, that is, elevated proton concentrations. The obtained result is in agreement with that obtained by Sert et al. (2008) who observed that HNO_3 was used as a reagent for desorption of La (III) and Ce(III) biosorbed by *P. orientalis* powdered leaf. The percentage of La^{3+} ions removal from REEs concentrate solution is to be 78%. Less removal of La^{3+} ions which occurred in REEs solution as compared to synthetic La^{3+} ions solution might be attributed to the presence or interference of other rare earths in the solution that compete with La^{3+} for binding sites on the biosorbent. Similar observation was also reported by Toy et al. (2013).

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