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Research Article

Equilibrium and Thermodynamic Studies on the Biosorption of Lead (II) by Living and Nonliving Biomass of *Penicillium notatum*

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This study aims to investigate the biosorption of Pb (II) by living and nonliving biomass of *Penicillium notatum*. *Penicillium notatum* PTCC 5074 was purchased from Iran Scientific-Industrial Research Organization in lyophilized form and after culturing in potato dextrose agar was propagated in Sabouraud dextrose broth medium. The highest adsorption by living and nonliving biomass (180.74 and 187.08 mg/g per dry weight of biomass, respectively) was at the Pb (II) concentration of 228 mg/L and ionic strength of 43 mg/L in terms of Ca^{2+} and 1.2 g/L biomass concentration. The optimum contact time and temperature in nonliving biomass were 37 hours and 32.5°C, respectively. Kinetic studies showed that Pb(II) adsorption in both cases follows a pseudo-second-order reaction. The adsorption process was consistent with the Langmuir model in the nonliving state, whereas the favourite models for the living state were Langmuir and Freundlich. Thermodynamic constants indicated that the adsorption process by nonliving and living biomass were exothermic and endothermic, respectively. The obtained results showed that *Penicillium notatum* in living and nonliving states is suitable for the development of an efficient and economic biosorbent for the removal of Pb (II) from aqueous environments.

1. Introduction

Contamination of aquatic systems with toxic heavy metal has become one of the most serious environmental problems today [1, 2]. Many industrial activities including electroplating, mining, tannery operations, battery factories, and chemical manufacturing release heavy metals to the environment [3, 4]. These toxic heavy metals cause serious threat to environment, animals, and human due to their bioaccumulation potential, persistency, and toxicity [3, 5]. The removal of these toxic heavy metals from aquatic environments is critical and urgent [6, 7]. Various treatment processes such as chemical deposition, ion exchange, membrane processes, extraction with solvent, adsorption with activated carbon, and evaporation are used to remove and separate heavy metals from water solutions [8–10]. Due to the high operating cost of ion exchange, reverse osmosis systems, and chemical processes as well as producing chemical sludge problems, the biosorption method can be used as an economical and environment-friendly alternative. Recently, there has been considerable interest in the use of microorganism-based biosorbent materials [11]. Biosorption includes all practical processes for the adsorption of heavy metals by the microorganisms' cells (bacteria, fungi, and algae) and the accumulation of heavy metal ions inside and outside of the cell [8, 12]. In this case, the heavy metals are removed through various mechanisms such as physical adsorption, ion exchange, and microsurface precipitation [13, 14]. Filamentous and yeast fungal biomasses have a great ability to adsorb metals among other microorganisms

[12, 15]. Fungi have received more attention due to their special cell wall and the presence of various organic compounds such as carboxylic groups, sugars, fats, and proteins, and active sites that have the ability to bind metal ions [16, 17]. Low cost and possibility of reuse, good adsorption capacity due to a high contact surface, selective adsorption of metal ions, and applicability in environmental conditions are the advantages of biosorption for metal ion removal in comparison with other physical and chemical methods [18]. Metal ions concentration, biomass volume, pH of solution, temperature, contact time, and ion strength are influencing parameters during the biosorption methods [19]. Lead (II) has high toxicity, and it is available in the effluent of various industries such as metal smelting welding and battery production [8, 20, 21]. Developing a new microbial biosorbent with high capacity to adsorb Pb (II) remains challenging. In this study, the main aim was to provide a novel microbial biosorbent with a high capacity to adsorb Pb (II), which can be used to remediate the water bodies that are contaminated with heavy metals. Then, we compared Pb (II) biosorption by living and nonliving biomass of *Penicillium notatum*.

2. Materials and Methodology

2.1. Preparation of Penicillium notatum Biomass. Lyophilized form of *Penicillium notatum* PTCC 5074 was purchased from Iran Scientific-Industrial Research Organization. The fungus was cultured on plates containing the specific medium of potato dextrose agar (PDA) and incubated at 28°C for 48 hours [22]. To increase the number of mycelium, 250 mL Erlenmeyer flasks containing 100 mL of Sabouraud dextrose broth (SDB) culture medium were used, and several colonies with the sterile loop were inoculated and then placed in a shaker incubator at 120 rpm and 28°C for 72 hours [22]. The biomass was separated from the broth medium using a centrifuge at 3000 rpm (15 min) [11]. Then, the supernatant was discarded. The precipitated biomass was washed three times with distilled water and used as living biomass [23]. To prepare nonliving biomass, after washing the deposited biomass, it was dried in oven at 60°C for 24 hours, powdered, and passed through a mesh of less than 100 μm and used as a nonliving biomass [22, 24].

2.2. Adsorption. Before starting the experiments, all of the dishes were placed in HNO_3 (10%) for 2 hours and were washed with distilled water [9]. The stocks solution of Pb(II) was prepared using Pb $(NO_3)_2$ [22]. NaOH and HNO_3 were used as pH adjustment chemicals [25]. Concentrations of 20, 43, 60, 77, and 100 mg/L of Ca^{2+} were used to determine the effect of ionic strength [23]. The specific amounts of dry biomass (0.3, 0.23, 0.17, 0.12, 0.05 g) were added to the samples and placed in an incubator shaker with 120 rpm and different temperatures (10, 23, 33, 42, 50°C) for 137, 105, 74, 30, and 180 min for nonliving and 2, 22, 37, 52, and 72 hours for living biomass. Finally, the samples were passed through Whatman # 1 filter paper, and the Pb (II) concentration of the filtered sample was measured by the atomic absorption spectrometer (AAS, F-240, VARIAN 240, Palo Alto, CA, USA). The amount of Pb (II) adsorption by this type of fungus was calculated using the following equation in mg/g dry weight.

$$q = (C_0 - C_e)\frac{V}{m}, \quad (1)$$

where C_e is the equilibrium concentration of the adsorbate in mg/L, C_0 is the initial concentration in mg/L, V is the volume of the solution in L, and m is the adsorbent mass in g [26].

2.3. Statistical Analysis. Statistical analysis was performed using the IBM SPSS statistics software, version 23. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Effect of Initial Concentration of Pb. Investigation of the effect of initial Pb (II) concentration on the adsorption rate showed that the adsorption rate of Pb (II) by nonliving biomass increased with increasing concentration ranged from 50 to 300 mg/L (Figure 1).

3.2. Effect of Ionic Intensity. The results of this study showed that the rate of adsorption by nonliving biomass decreased with increasing ionic strength in the range of 20–100 mg/L Ca^{2+}. However, in living biomass, changes in ionic strength did not have much effect on the amount of adsorption, and this decrease in adsorption was not statistically significant ($p > 0.05$) (Figure 2).

3.3. Effect of Biomass Concentration on Adsorption. The results indicated that with increasing biomass concentration in the range of 0.5–3 g/L (dry weight of biomass), the Pb (II) adsorption has decreased in both nonliving and living conditions (Figure 3).

3.4. Effect of Temperature. The amount of metal adsorption by living biomass first increased and then decreased in the temperature range of 10–50°C based on the results (Figure 4). But in nonliving biomass, it has caused a slight increase in adsorption, which is not statistically significant ($P > 0.05$).

3.5. Effect of Contact Time. The time variable had an effect on the Pb (II) adsorption by living biomass and increasing the contact time increased the adsorption (Figure 5(a)). However, Figure 5(b) shows that increasing the contact time in nonliving biomass caused a slight increase in adsorption and the highest metal adsorption occurred in the first 30 min.

Optimal comparison of Pb (II) adsorption in both nonliving and living conditions showed that the rate of metal adsorption by living biomass of *Penicillium notatum* (187.08 mg/g dry weight of biomass) was higher than that of nonliving biomass (180.75 mg/g dry weight of biomass). The reason for this increased adsorption in the living state is

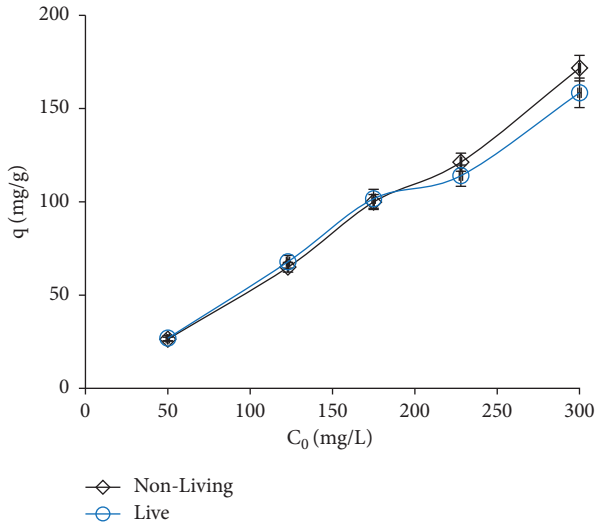

Figure 1: Effect of Pb (II) concentration on the biosorption process by *Penicillium notatum* (pH: 5).

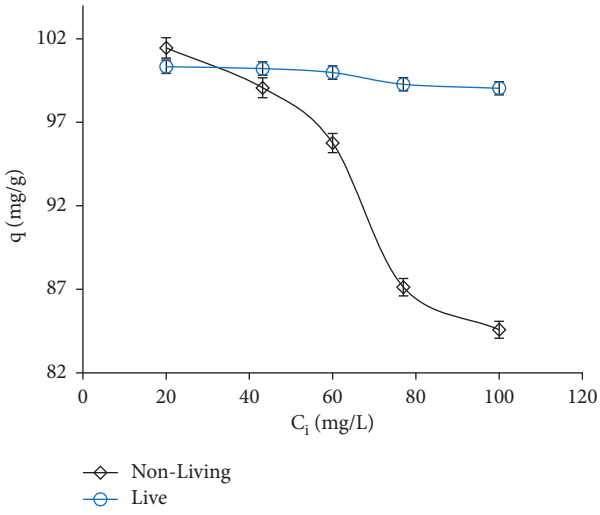

Figure 2: Effect of ionic intensity on the uptake of Pb (II) by *Penicillium notatum* (pH: 5).

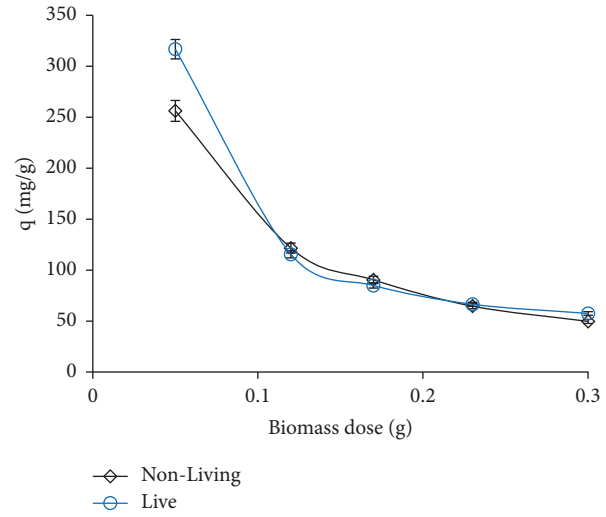

Figure 3: Effect of biomass concentration on the uptake of Pb (II) by *Penicillium notatum* (pH: 5).

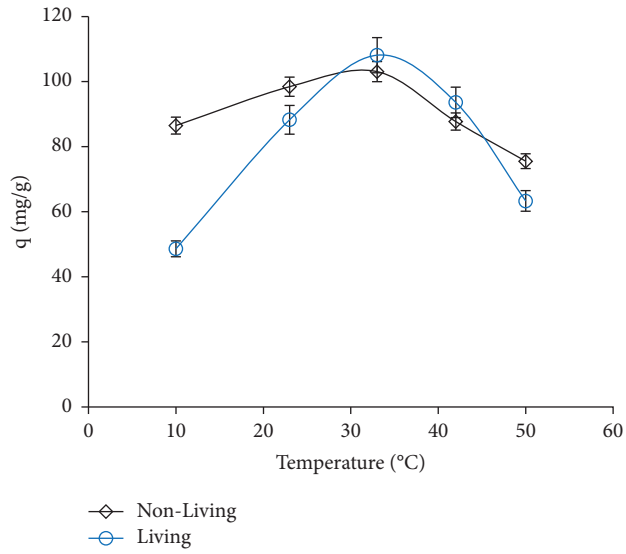

Figure 4: Effect of temperature on the uptake of Pb (II) by *Penicillium notatum* (pH: 5).

probably due to internal adsorption and biological accumulation (Figure 6).

3.6. Adsorption Isotherms. Adsorption isotherm is one of the important factors in designing the adsorption systems. This parameter is a key factor in determining the capacity of an adsorbent and optimizing the adsorbent consumption [27]. In this study, Langmuir and Freundlich adsorption isotherms were used to investigate the adsorption mechanism [28–30]. The linear equation of the Langmuir isotherm is given in the following equation:

$$\frac{C_e}{q_e} + \frac{1}{q_m \times b} + \frac{C_e}{q_m}, \tag{2}$$

where q_e is the amount of adsorbate per unit mass of adsorbent in mg/g, C_e is the equilibrium concentration of adsorbent in solution after adsorption in mg/L, and q_m and b are the Langmuir constants that are obtained in the curve (C_e/q_e) vs. C_e. The Freundlich isotherm linear equation is as follows:

$$\log q_e - \log K = \frac{1}{n} \log C_e, \tag{3}$$

where q_e is the adsorption capacity at equilibrium in mg/g, C_e is the equilibrium concentration of the adsorbent in mg/L, and K and n are the Freundlich constants obtained in the curve $\log q_e$ vs. $\log C_e$, [26, 31].

Adsorption isotherm models for nonliving *Penicillium notatum* were performed at pH = 5, contact time 131 min, adsorbent values of 0.03–0.35 g per 100 mL, Pb (II) concentration of 228 mg/L, and ionic concentration 43.2 mg/L at 23°C. The conditions for adsorption isotherm models for

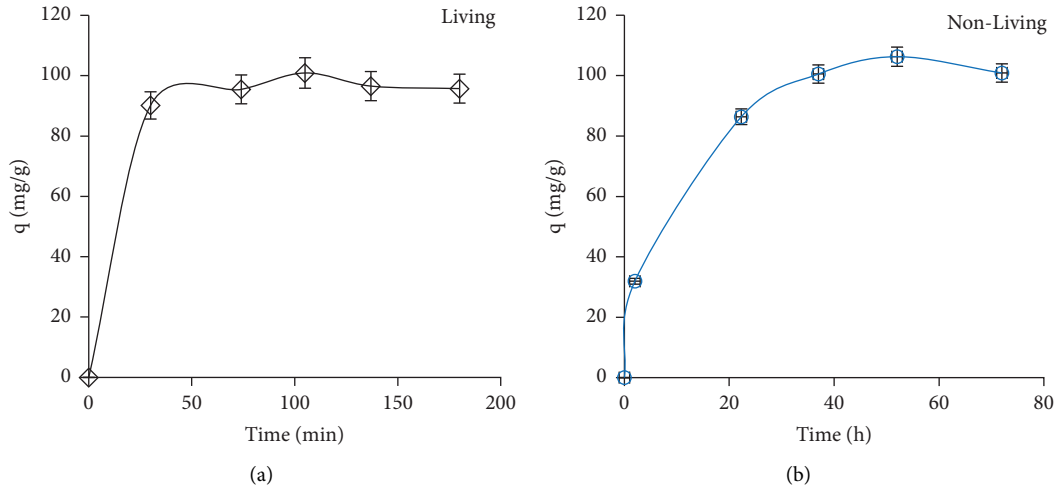

Figure 5: Effect of time on Pb (II) uptake by *Penicillium notatum* in living (a) and nonliving state (b) (pH: 5).

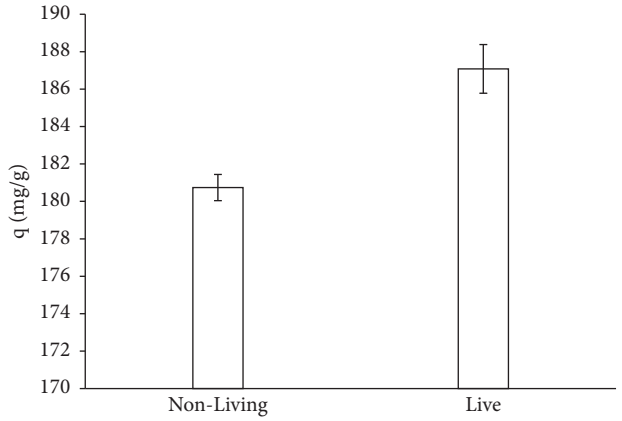

Figure 6: Comparison of Pb (II) uptake by nonliving and living biomass of *Penicillium notatum*.

living *Penicillium notatum* were the same as for nonliving conditions, except that the contact time was 51.30 h and the temperature was 42°C.

The results showed that the adsorption in nonliving biomass follows the Langmuir model ($R^2 = 0.982$), and the maximum adsorption was 178.6 mg/g dry weight of the fungus. Moreover, adsorption in living biomass also follows the Langmuir and Freundlich models ($R^2 = 0.982$ and $R^2 = 985$), and the maximum adsorption is 181.8 mg/g dry weight of fungi (Table 1 and Figure 7).

3.7. Thermodynamic. Thermodynamic studies help to better understand the adsorption process and apply measures to increase the adsorption efficiency. Thermodynamic parameters include Gibbs-free energy (ΔG^0), enthalpy (ΔH^0), and entropy (ΔS^0), indicating the feasibility and spontaneity of the process, whether the reaction is superheated or exothermic, and the changes in standard Gibbs-free energy, enthalpy, and entropy. The following equation is used to obtain ΔG^0:

$$\Delta G^0 = -\mathrm{RTL}_n b, \tag{4}$$

where R is the universal gas constant ($\mathrm{Jmol^{-1}k^{-1}}$), T is the temperature in $^{\circ}K$, and b is the process equilibrium constant. The values of ΔH^0 and ΔS^0 can be determined based on the Van Hoff equation and by plotting the chart in $1/T$ (equation (5)) [26].

$$\mathrm{Ln}(b) = -\frac{\Delta G^0}{RT} = \frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R}. \tag{5}$$

Table 2 presents the thermodynamic parameters values obtained. Considering the negativity of all ΔG^0 in the living and nonliving state, it is clear that all adsorption processes are spontaneous. Additionally, the result relevant to the values of Gibbs-free energy for both nonliving and living states are more than −20 kJ/mol, which shows that the adsorption processes are physical.

3.8. Kinetic Study. The study of reaction kinetics provides information about the reaction rate and the mechanism by which reactants are converted into products. Rate equations can be expressed as expressions that relate concentration to time. In the zero-order reaction, the rate of production of secondary materials is not a function of the concentration of raw materials. In the first-order reaction, the reaction rate is proportional to the initial concentration of the reactant, and the removal rate depends on the initial concentration. However, the reaction rate is proportional to the second order of the metal concentration in the second-order reaction [32]. Table 3 shows the kinetics equations.

In Table 3, C_0 (mg/L) is the concentration at time zero, C_t (mg/L) is the concentration at time t, and k is the velocity constant. The zero, first, and second orders of changes in $[C_t]$, $(\mathrm{Ln}[C_t]/[C_0])$, and $(1/[C_t])$ are plotted vs. time to determine the velocity constant in terms of different equations. The correlation coefficients are provided in Table 4. Based on the results, the process kinetics of nonliving and living states were of the second-order type.

Table 1: Fixed and correlation coefficients of Langmuir and Freundlich isotherms (nonliving and living biomass).

Isotherms	Isotherm equations	Fixed coefficients and correlation coefficients of isotherms					
		q_m (mg·g)		K_L		R^2	
Langmuir	$(1/q_e) = (1/q_m k_L C_e) + (1/q_m)$	Live	Nonliving	Live	Nonliving	Live	Nonliving
		187.08	180.75	0.035	0.011	0.987	0.982
		K		$(1/n)$		R^2	
Freundlich	$\text{Log}q_m = \text{Log}K + (1/n)\text{Log}C_e$	Live	Nonliving	Live	Nonliving	Live	Nonliving
		6.6	6.7	0.7	0.6	0.998	0.865

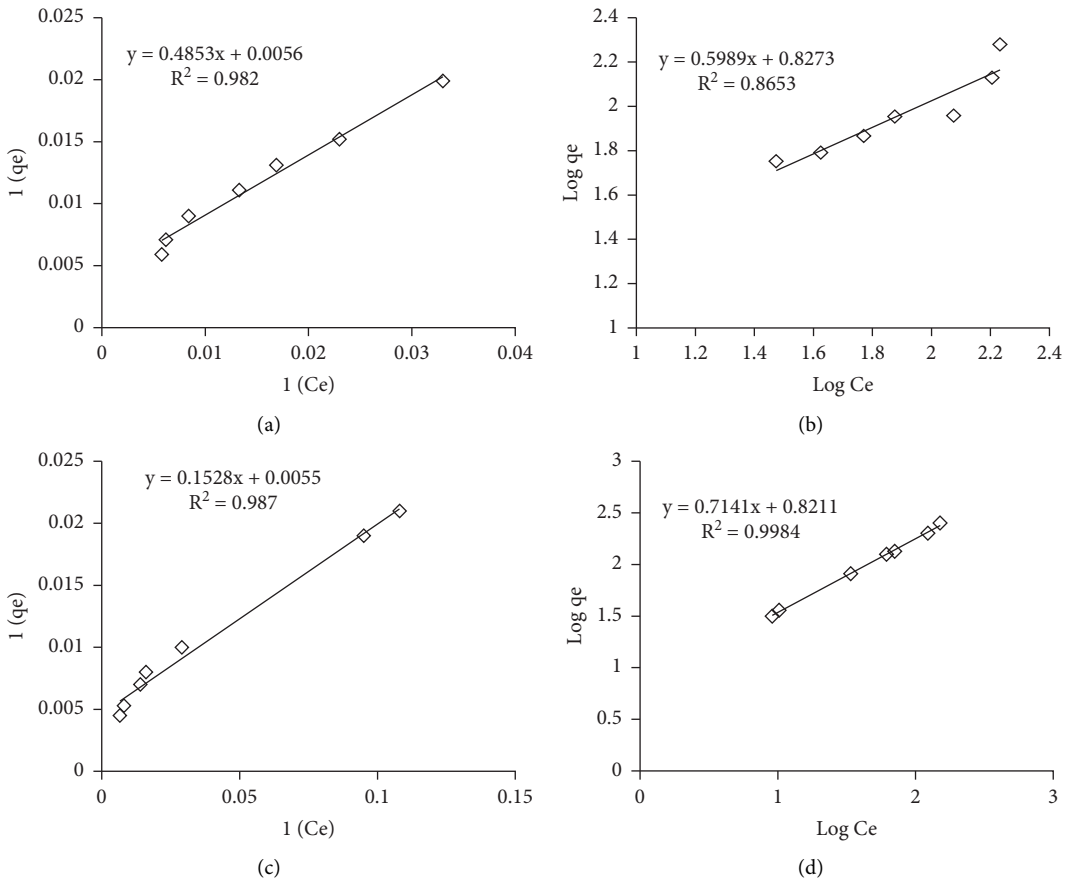

Figure 7: Isothermal models of the Pb (II) adsorption process by nonliving and living biomass of *Penicillium notatum*. (a) Langmuir, living state. (b) Freundlich, living state. (c) Langmuir, nonliving state. (d) Freundlich, nonliving state.

4. Discussion

4.1. Effect of Initial Concentration. The results showed that the amount of adsorption increased with increasing Pb(II) concentration in solution. The reason for this issue is that the active sites of the fungus are surrounded by more metal ions, which leads to the maximum metal ion adsorption capacity [9, 25]. On the other hand, increasing the concentration of metal ions increases the number of contacts between metal ions and adsorbents and then accelerates the adsorption process [17]. Optimizing the Pb(II) adsorption process by nonliving biomass of *Penicillium notatum* showed that the maximum metal adsorption capacity was 228 mg/L Pb(II). The results of different studies on the Pb(II) biosorption by the nonliving biomass of *Penicillium, Aspergillus flavus*, and *Aspergillus niger* are consistent with this study [8, 22, 25]. The obtained results on the biological adsorption of Pb(II) by living biomass were consistent with the results of Farhan and Khadom and Amirnia et al. where increasing the concentration of the metal increased the rate of biological adsorption [9, 33]. Also, the results are consistent with Yarke Sakhori et al. and Iskandar et al. studies [34, 35].

4.2. Effect of Ionic Intensity. The results of the present study showed that the adsorption capacity of Pb(II) by nonliving biomass decreased with increasing ionic strength. The mean adsorption at concentrations of 20 and 100 mg/L of Ca^{2+} by nonliving biomass was equal to 101.46 and 84.58 mg/g dry weight of biomass, respectively. This reduction may be due to infraction between Ca^{2+} and Pb(II) in adsorption sites [21]. These results are consistent with Zhang et al. [24],

Table 2: Thermodynamic parameters of Pb (II) uptake by *Penicillium notatum* in the nonliving state.

$T(^{\circ}K)$	ΔG^0 (j/mol)		ΔH^0 (j/mol)		ΔS^0 (j/mol)	
	Nonliving	Live	Nonliving	Live	Nonliving	Live
283	−1019.74	−470.6				
296	−1156.6	−487.3				
306	−636.1	−585.14	−8064	1511	−24.2	6.87
315	−366.7	−654.7				
323	−241.7	−725.06				

Table 3: Kinetics equations.

Order	Equation	Linear model
Zero	$[C_t] - [C_0] = -kt$	$[C_t]$
First	$\mathrm{Ln}([C_t]/[C_0]) = +kt$	$(\mathrm{Ln}[C_t]/[C_0])$
Second	$(1/[C_t]) - (1/[C_0]) = kt$	$(1/[C_t])$

Table 4: Correlation coefficient values of adsorption velocity equations in the nonliving and living state.

Order	Correlation coefficient		Speed constant ($1\ \mathrm{min}^{-1}$)	
	Nonliving	Living	Nonliving	Living
Zero	0.8966	0.8712	0.0117	1.595
First	0.8483	0.8711	0.0004	0.0101
Second	0.994	0.9966	0.0002	0.0038

Sepehr et al. [23], and Lodeiro et al. [36] studies. They reported that metal adsorption capacity decreases with increasing ion intensity due to the competition of electrolyte ions in adsorption sites [36, 37]. El-Sayed et al. concluded that increasing the amount of 1 to 10 g/L of NaCL slightly reduced the adsorption of Cd and Ni by rice bran [38].

We also observed that the adsorption capacity of Pb(II) by living biomass decreased as ionic strength increased.þ However, this decrease was not statistically significant ($p > 0.05$). Because increasing the Ca^{2+} from a concentration of 20–100 mg/L has reduced the adsorption of Pb (II) from 100.32 to 99.04 mg/g. Glatstein et al. study indicated that the ionic strength had little effect on the Cu and Pb (II) removal from water by sodium bentonite adsorbent [39]. Nourmoradi et al. also demonstrated that increasing the ionic strength in solutions had no significant effect on the removal of monoaromatic hydrocarbons including benzene, toluene, ethylbenzene, and xylene [40]. Contrary to the above results, Lin et al. showed that increasing Ca^{2+} from zero to 1 mmol/L increased PO_4^{3-} adsorption from 47.9 to 70.3 mg/g by ZrO_2 [41]. Given that no similar study was found on the effect of ionic strength on the biological heavy metals and adsorption by living biomass, the pH of the solution seems effective. Also, the amount of Ca^{2+} added to the samples may not show a significant effect. Liu et al. emphasized the involvement of Ca^{2+} in important fungal processes such as cell-cycle evolution, hyphae growth, sporulation, and spore germination [42]. In this study, the optimization steps of Pb (II) adsorption by nonliving and living biomass of *Penicillium notatum* showed that the maximum metal adsorption capacity was associated with 43.2 mg/L Ca^{2+} concentration.

4.3. Effect of Nonliving and Living Biomass Concentration. The results of this study showed that the biological adsorption capacity of Pb(II) decreased with an increase in the adsorbent concentration. At concentration of 0.5 g/l, the average adsorptions by nonliving and living biomass were 256.2 and 316.73, respectively, while at concentration of 0.3 g/l, the averages were 49.66 and 57.55 mg/g of biomass dry weight, respectively. This effect is due to the interaction between the binding sites at higher concentrations of biomass. Moreover, the imbalance of soluble metal ions in relation to the available places for bonding and the lack of complete coverage on these sites reduce the adsorption [22, 43]. The results of this study are consistent with the results of Farhan and Khadom and Fan et al.' studies [9, 22]. In different studies, increasing the concentration of biomass reduced the biological adsorption of heavy metals [8, 23, 44].

The results of equilibrium isotherm studies showed that the adsorption process of Pb (II) by nonliving biomass of *Penicillium notatum* followed the Langmuir isotherm ($R^2 = 0.98$), and the maximum adsorption capacity was 178.6 mg/g. This means that Pb (II) adsorption occurs at certain homogeneous locations, and a monolayer adsorption occurs on the adsorbent surface. The results of this study in nonliving biomass state are consistent with Iram et al. and Ahmad et al.' studies, while in Marandy et al.' study, the Pb (II) and Zn adsorption by Phanerochaete chrysosporium nonliving biomass followed the Langmuir and Freundlich isotherm models [19, 25, 44]. Also, the results showed that the Pb (II) adsorption process by living biomass of *Penicillium notatum* follows both Langmuir ($R^2 = 0.98$) and Freundlich ($R^2 = 0.99$) isotherm models, and the maximum adsorption capacity was 181.8 mg/g. These results are consistent with Farhan and Khadom, Joshi et al., and Tsekova et al.' studies [9, 11, 45].

4.4. Effect of Temperature on Adsorption Capacity. The present study showed that with increasing temperature, the adsorption capacity of Pb (II) by nonliving biomass first increased and then decreased. The mean adsorption capacities by nonliving biomass at 10, 23, 32.5, 42, and 50°C were 86.5, 98.45, 103.83, 87.74, and 75.55 mg/g, respectively. In this study, the optimal temperature for maximum adsorption by nonliving biomass was 32.5°C. In general, temperature affects the biosorption of metal ions in a certain range. This may be due to increasing kinetic energy and greater contact of the adsorbent surface and metal ions [46]. However, since adsorption reactions are naturally exothermic, biosorption decreases with more increase in temperature [34]. On the other hand, the decrease in adsorption capacity at higher temperatures indicates that the adsorption of metal at very high temperatures is reduced due to changes in some of the metal binding sites at the cell surface [47, 48]. Also, the active binding site on the biomass surface is damaged and changed by increasing temperature. This phenomenon reduces the adsorption at high temperatures [8, 9, 49]. Wang stated that when the nature of adsorption is exothermic, increasing the temperature will decrease the adsorption capacity of biomass [48]. Also, the results of this

study showed that the amount of biological adsorption of Pb(II) by living biomass increased with increasing temperature, although this increase was not statistically significant ($p > 0.05$).

This initial increasing in adsorption may be due to kinetic energy increase, surface activity, and number of contacts between biomass and metal ions. Also, the destruction of connections at higher temperatures and the increase of bondable places have been effective in this occurrence. These results are consistent with Baysal et al.' study, on the slight increase in adsorption from 828 to 833 mg/kg (dry weight of biomass) at 20–45°C [8]. Marandy et al. concluded that increasing the temperature from 20 to 45°C enhances the Pb (II) adsorption by Phanerochaete chrysosporium, but this increase was negligible [44]. In this study, the optimum maximum adsorption temperature in living biomass was 32.5°C, which was not significantly different from 23°C.

According to the observed results, Farhan and Khadom and Yarke Sakhouri et al. concluded that the increase in temperature increased the adsorption and the optimum temperature for maximum Pb(II) removal by living yeast *Saccharomyces cerevisiae* was 27 and 28°C [9, 34]. Ahmadi-Asbchin et al. also reported the optimum temperature of 25°C for the removal of heavy metals by living *Saccharomyces carlsbergensis* [49]. In this study, the adsorption thermodynamics experiments were investigated in the temperature range of 10–50°C. According to the obtained results in Table 2 and the negativity of ΔG^0 for Pb (II), it is clear that all adsorption processes are spontaneous. Besides, increasing ΔG^0 with raising the temperature in the living state indicates an increase in the degree of spontaneity of the adsorption process with increasing temperature. In this study, Gibbs-free energy values for both living and nonliving adsorbent states were greater than −20 kJ/mol, and it can be concluded that the adsorption processes are physical. The negative enthalpy of adsorption reactions on the nonliving adsorbent indicates that this process is exothermic, but the enthalpy of the adsorption reaction on the living adsorbent is positive and endothermic. The entropy changes in adsorption by the nonliving adsorbent are negative and indicate the fact that the degree of release at the solid-soluble surface decreases during adsorption. However, entropy changes in adsorption are positive and indicate an increase in the irregularity on the solid-solution surface during the adsorption process and a slight structural change in the adsorbent and adsorbate, resulting in the irreversibility of adsorption [13]. Different studies indicated that Pb (II) adsorption on the nonliving *Candida albicans* and *P. simplicissimum*. was spontaneous and endothermic [9, 22].

4.5. Effect of Contact Time and Adsorption Kinetics. In this study, the adsorption capacity of Pb (II) by *Penicillium notatum* biomass was investigated in the range of 30–180 min for nonliving biomass and 2–72 h for living biomass. It was found that with the increase in contact time, the absorbability of nonliving biomass increased, but this increase was not statistically significant ($p > 0.05$). The results showed that the main metal adsorption was occurred in the first 30 min.

This indicates that the adsorption can be due to the availability of active adsorbent sites that decrease over time [9]. The short equilibrium time of nearly 30 min provides the proper efficiency of the fungus in the industrial wastewater treatment, and this issue can indicate the use of biological methods in heavy metals removing from industrial wastewater in the short term [49].

In this regard, Baysal et al. reported an optimal time of 10 min for maximum Pb (II) adsorption by the nonliving *Candida albicans* [8]. Also, Marandy et al. stated that the appropriate time for maximum Pb (II) adsorption by the nonliving biomass of Phanerochaete chrysosporium is one hour [44]. In this study, the optimal contact time for the living state was 37 h, and after this time, the adsorption rate decreased due to the saturation of the active sites of the adsorbent surface. The reason for this decrease is intracellular metal adsorption and biological accumulation due to long contact time because biological accumulation is a process that is slow and depends on metabolism and cell growth [34]. Also, Farhan and Khadom and Yarke Sakhuri et al. showed that the biological adsorption of Pb (II) by *Saccharomyces cerevisiae* increases with increasing contact time [9, 34]. Kinetics studies showed that adsorption kinetics followed a pseudo-second-order reaction in both nonliving and living cases ($R^2 < 0.99$). Ahmed et al. and Baysal et al. reported that the adsorption kinetics of heavy metals by Candida albicans and Candida tropicalis followed a pseudo-second-order reaction [8, 19].

5. Conclusion

The results of Pb (II) adsorption experiments from water solution showed that the maximum adsorption efficiency under optimal conditions for nonliving biomass was 180.75 mg/g dry weight of biomass. The adsorption mechanism in nonliving biomass followed the Langmuir isotherm. The maximum adsorption efficiency under optimal conditions by biomass was 187.08 mg/g dry weight and the adsorption mechanism followed the Langmuir and Freundlich isotherms. The obtained thermodynamic constants indicated that Pb (II) adsorptions by living and nonliving biomass are endothermic and exothermic, respectively. Also, the adsorption kinetics of Pb (II) by both of the biomasses followed the pseudo-second-order reaction. According to the results, Pb (II) removal using biosorption by *Penicillium notatum* in living and nonliving states is important due to low-cost, high adsorption capacity, simple and environment-friendly management, selective adsorption of metal ions in the living state, application in environmental conditions, and the good removal efficiency. Although the results are very promising as a starting point for a potential application of live and nonliving biomass *Penicillium notatum* as an efficient and economic biomaterial for the removal of Pb (II) from metal-contaminated wastewaters, the development and further investigations are still needed.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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