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# Utilization of Lemon Peel Adsorbent for Efficient Nickel Removal from Synthetic Wastewater

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Heavy metals in water are considered pollutants and represent a worldwide environmental issue. Common heavy metal ions with high toxicity and carcinogenicity, such as nickel, are often found in contaminated water. The increasing presence of human-made sources of nickel, introduced into water bodies through industrial discharge, agricultural runoff, and wastewater treatment plants, as well as natural sources, underscores the importance of removing nickel from water before consumption. Adsorption is a widely used method for removing nickel ions from contaminated water. Different adsorbents have been produced from waste of various materials and applied to eliminate nickel ions. In this study, natural biosorbent was prepared using lemon peel to remove nickel ions from simulated wastewater in a batch reactor mode. Various parameters influencing the adsorption process of the current study were examined. These parameters involved the application of a pH value range of 2 to 7, a contact time range of 30 to 120 minutes, and an adsorbent mass range of 0.25 g to 3 g per 100 mL, with a constant initial concentration of nickel (II). Scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) were used to analyze and evaluate the surface and the functional groups of the raw and used adsorbent. Significant changes in the surface morphology of the used adsorbent were observed, indicating high adsorption of nickel ions. The influence of the temperature on the adsorption process was also investigated. The results elucidated that increasing the temperature enhanced the nickel (II) removal percentage, suggesting that the process is endothermic. Moreover, different isotherm models and kinetic parameters, such as Langmuir and Freundlich, were used to further describe the adsorption characteristics of the biosorbent. Overall, the results indicate that lemon peel shows significant potential as a low-cost biosorbent for removing nickel (II) ions.

**Keywords:** adsorption isotherms, adsorption kinetics, biosorbent, nickel removal.

## Introduction

Water is a limited natural resource. Stress imposed by growing populations and industrial activity is a threat to this natural resource regarding both quality and quantity (Mohammed et al., 2023; Al-Satar and Sachit, 2021a). The quality of the naturally existing water continues to deteriorate as a result of the increased amount of wastewater discharged into the rivers, lakes, and groundwater systems, often without adequate treatment. This wastewater introduces various harmful substances that negatively impact the ecosystem health (Mahdi et al., 2023; Kulkarni et al., 2022; Mohammed et al., 2022; Al-Satar and Sachit, 2021b). Among these contaminants, heavy metals such as cadmium, lead, mercury, arsenic, and nickel are considered the most dangerous types of pollutants because they can cause many health problems (Hameed and Alatabe, 2022; Ali et al., 2020a; Rao et al., 2010). Nickel is widely distributed on Earth, and it is a chemical element that has a molecular weight of 58.69 g/mol. Due to its properties, nickel is utilized in various industries such as in the synthesis of alloys, electroplating processes, manufacturing of batteries, petroleum refining, production of organic chemicals, and many other applications (Alsarayreh et al., 2025; Hamdan et al., 2024a). It is also an essential element for human health. According to the World Health Organization (WHO), the maximum allowable limits of nickel in drinking water and treated wastewater are 0.02 mg/L and 900 mg/L, respectively (Wołowicz and Wawrzkiewicz, 2021). The recommended daily intake of nickel for adults is generally around 20–50 µg (Yasmin et al., 2015; Thakur and Parmar, 2013). For workers exposed to nickel in industrial sites, the U.S. Occupational Safety and Health Administration (OSHA) sets the permissible exposure limit (PEL) to 1 milligram per cubic meter of air for soluble nickel compounds over an 8-hour workday. However, exposing to large quantity of nickel can lead to kidney and lung diseases, coughing, chronic asthma, skin dermatitis, risk of cardiovascular disease as well as increasing the risk of lung and nasal cancer (Alsarayreh et al., 2025; Wołowicz and Wawrzkiewicz, 2021). Furthermore, increasing human-made sources of nickel, which enter water bodies through industrial discharge, agricultural runoff, and wastewater treatment plants, as well as natural sources, have increased its levels in water and wastewater (Kusumaningsih et al., 2024). Therefore, elimination or reduction of the concentration of nickel in contaminated water through advanced treatment processes is essential for maintaining human and environmental safety at the same time.

Removal of nickel from contaminated water can be achieved using various physicochemical techniques, ranging from conventional techniques, such as chemical precipitation, electrochemical treatment, and filtration, to nonconventional treatment methods, such as ion exchange and membrane processes. However, these methods have high initial set up cost, and sometimes they are less effective when high concentration of nickel (II) ions is present (Kulkarni et al., 2022; Wołowicz and Wawrzkiewicz, 2021). Unlike chemical precipitation, most adsorption processes do not generate excess sludge or other waste products, making it an environmentally friendly option. In addition, the membrane process, as another technique to separate metals from water, uses high driven pressure that consumes a large amount of fuel compared with adsorption process (Kariem et al., 2018). Furthermore, some adsorbents, such as activated carbon, can be regenerated and reused multiple times, reducing operational costs in the long term. Overall, considering both advantages and disadvantages, the most practical technique for nickel removal is adsorption (Wołowicz and Wawrzkiewicz, 2021). The adsorption process can produce water with contaminant levels that meet the effluent regulations and water reuse needs (El Yakoubi et al., 2023; Ali, 2017). Although activated carbon is the most commonly used adsorbent, it is not often employed in large scale processes due to its high cost. Numerous studies have investigated inexpensive adsorbents made from various wastes and product residues (Alatabe, 2023; Alatabe et al., 2021; Alwared et al., 2021; Ali et al., 2020b; Al-Sharify et al., 2018).

Agricultural wastes are used as adsorbents, which are attractive due to their abundance, affordable cost, unique particle structure, and high concentration of particulate carbon. Polysaccharides, which are the main functional group found in cell walls of the biosorbent, highly impact the sorption process (Hamdan et al., 2024b). In addition, carboxyl groups of algal sorbents may actively participate in the sorption of metals (Ali, 2016; Bhatnagar et al., 2010). The polysaccharide found in cell walls (pectin) is primarily composed of galacturonic acid. The polysaccharide contains a large number of carboxyl groups, which have a high ability to incorporate bivalent cations (metals), thereby enhancing the effectiveness of pectin. Numerous pectin-rich substances have been investigated for their potential to bind metals, such as apple waste, coffee husks, and various fruit materials, including different varieties of citrus peel (Al-Qaisi et al., 2018; Ali, 2016). Furthermore, lemon peel as natural adsorbent has been widely studied for removing heavy metals, such as selenium, zinc, cyanide, copper, and phosphate, from wastewater (Alsarayreh et al., 2024; Al-Hermizy et al., 2022; Alalwan et al., 2020; Al-Qaisi et al., 2018; Ali, 2016). The viability of using lemon peel as an inexpensive adsorbent material for the removal of nickel (II) from contaminated water is presented in this study. Investigations were conducted into factors that could affect biosorption, including pH, contact time, biosorbent mass, temperature, and thermodynamic parameters. Additionally, various isotherm models and kinetic parameters such as Langmuir and Freundlich were investigated for the nickel (II) biosorption process. Furthermore, scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) were used to analyze and evaluate the surface and the functional groups of the raw and used adsorbent.

## Methods

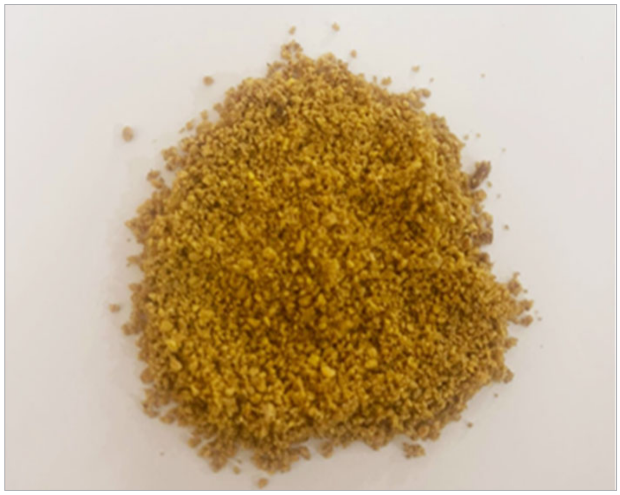
Waste from a local juice marketplace was used to collect lemon peel, which was cleaned with distilled water to remove surface contaminants and then baked for 24 hours at 100°C to eliminate any remaining moisture. After that, dried lemon peel was ground and sieved, and particles with sizes of 0.5 mm or less were extracted. Ground lemon peel that was used in the experiments is shown in *Fig. 1*.

In order to prepare simulated wastewater containing nickel (100 mg/L), nickel nitrate ($N_2NiO_6 \cdot 6H2O$) was dissolved in deionized water, and the required weight of nickel nitrate was estimated using Eq. (1) (Schiewer and Volesky, 1997):

$$W = V \times C_i \times (\frac{M_{wt}}{A_{t.wt}}) \quad (1)$$

In Eq. (1), $M_{wt}$ represents the molecular weight of nickel nitrate (g/mol), $A_{t.wt}$ represents the molecular weight of the nickel ion (g/mol), W denotes the mass of nickel nitrate in (mg), V symbolizes the required volume of simulated wastewater in (L), and Ci denotes the prepared concentration of nickel in simulated wastewater (mg/L). The molecular weights (M.wt) of nickel nitrate and nickel ions are 290.81 g/mol and 58.69 g/mol, respectively. The following formulas were applied to calculate the weight of nickel nitrate that gives a concentration of nickel cations ($Ni^{+2}$) of 100 mg/L in distilled water (Schiewer and Volesky, 1997; Khan et al., 2011):

**Fig. 1.** *Ground lemon peel*



$$Ni(NO_3)_2 \cdot 6H_2O \rightarrow N_i^{+2} + 2NO_3^{-1} + H_2O \quad (2)$$

$$w = 1\,(L) \times 100\,\left(\frac{mg}{L}\right) \times \frac{290.81\left(\frac{g}{mole}\right)}{58.81\left(\frac{g}{mole}\right)} = \quad (3)$$

$$= 494.49\,mg \text{ of } Ni(NO_3)_2 \cdot 6H_2O$$

### Batch experiments

The experiments of batch sorption were conducted to detect the optimum parameters of the sorption process, such as adsorbent dose, pH, contact time, models of equilibrium, and isotherms of kinetic. A concentration of 0.1N of both hydrochloric acid and sodium hydroxide was used to adjust the pH of the prepared solution. At a speed of 200 rpm, the prepared solution was stirred for a specific duration. Then, the simulated wastewater was mixed using a mechanical shaker with a constant speed. Finally, lemon peel was separated from the supernatant by the filtration process. The concentration of residual ions was measured by atomic absorption spectrophotometer (AAS) (GBC933 Plus, Australia). The adsorption efficiency of the used lemon peel to remove nickel ions was determined according to the following formula (Schiewer and Volesky, 1997):

$$R\% = (C_i - C_f) / C_i \times 100 \quad (4)$$

where R represents the nickel removal percentage, and $C_i$ and $C_f$ are the initial and final concentrations of the nickel ion, in mg/L.

### Adsorbent characterization

The changes in the surface morphology of the adsorbents before and after the adsorption process can be identified by analyzing the functional groups present on the adsorbent's surface; this can be determined by analyzing the spectra of FTIR spectroscopy (Hameed et al., 2025). The lemon peel adsorbent was analyzed using FTIR spectra and SEM images. FTIR analysis is necessary to identify the functional groups of lemon peel responsible for metal ion adsorption. In materials science, SEM is a widely used research technique to investigate molecular shape, porosity, and size distribution of adsorbents' surfaces (Khan et al., 2011; Ruthven, 1984; Kuh and Kim, 2010; Ali et al., 2024). SEM images were obtained before and after the sorption process.

## Results and Discussion

### FTIR and SEM analyses

*Fig. 2* shows spectra of raw and used lemon peel adsorbent over a range of measurements. The range of 4000–400 $cm^{-1}$ in wavenumber displayed peaks at 3387.00 $cm^{-1}$ and 2927.94 $cm^{-1}$ corresponding to O–H stretch (Ruthven, 1984). Also, peaks of 1732.08 $cm^{-1}$ and 1627.92 $cm^{-1}$ were shown because of C=O stretch. In addition, peaks of 1450. 47 $cm^{-1}$, 1330.88 $cm^{-1}$, 1041.56 $cm^{-1}$, and 759.92 $cm^{-1}$ attributed to C–H stretching were presented. Moreover, peaks around 659.66 $cm^{-1}$ and 547.78 $cm^{-1}$ represent Ni–O bonds and Ni–O–H bonds. The presence of numerous peaks representing different functional groups in the FTIR spectra indicates a complex morphology of the adsorbent's (lemon peel) surface after the adsorption process, as compared with that of the raw adsorbent.

According to the SEM studies, there are numerous heterogeneous pore layers in lemon peel. These heterogeneous and porous surfaces are thought to be essential for the adsorption of heavy metal ions (Ruthven, 1984). The SEM image in *Fig. 3* illustrates the surface structure of adsorbents before and after the adsorption process. The surface of the adsorbent after the adsorption process

**Fig. 2.** *FTIR spectra of lemon peel before and after the adsorption process of nickel ions*

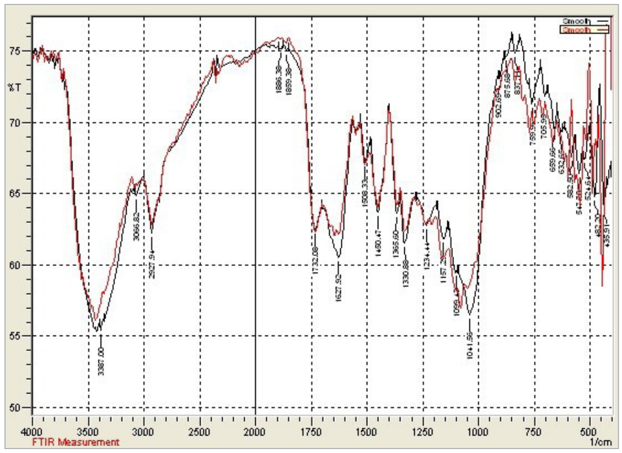
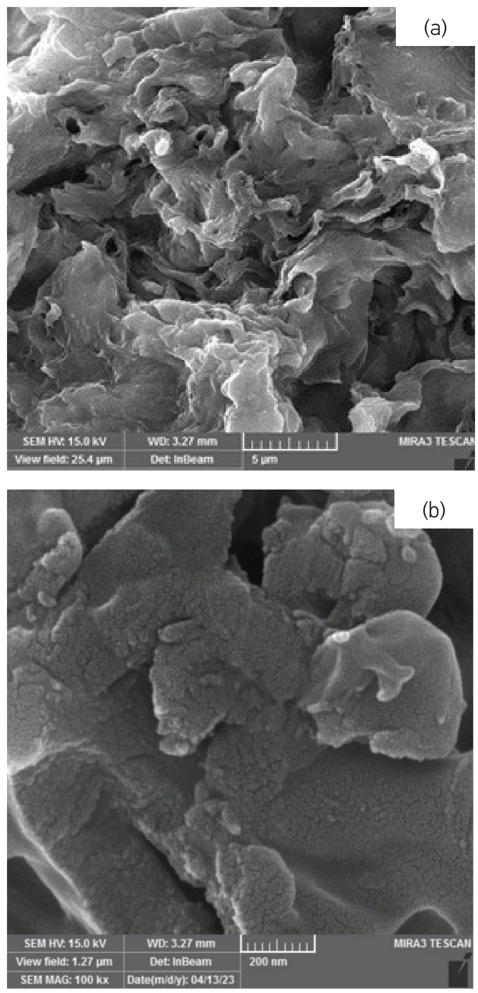



**Fig. 3.** *SEM images of the surface's morphology of raw (a) and used (b) lemon peel*

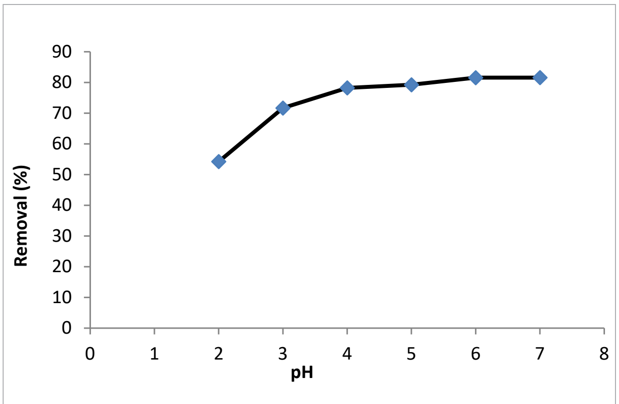


appears smoother compared with that before the adsorption process. SEM images and FTIR analysis reveal notable changes in the surface morphology of the used adsorbent, indicating high adsorption of nickel ions.

## Impact of pH

The pH of water significantly influences metal uptake. The pH of the solution affects both the metal chemistry in solution and the metal binding sites on the biosorbent material surface. Metal removal is reduced at low pH levels, which is attributed to the increase of $H^+$ ions, thereby decreasing the ability of metal cations to occupy binding sites on the adsorbent surface (Abbas et al., 2019). To investigate the effect of pH levels on nickel removal by lemon peel as a bioadsorbent, batch tests were conducted across pH ranges of 2 to 7 at room temperature. The results (*Fig. 4*) showed that pH of 6.0 was optimal. According to certain theories, under highly acidic conditions, adsorbent surface ligands strongly associate with $H_3O^+$, resulting in repulsive forces that prevent metal ions from accessing the functional groups. It is understood that as pH levels increase, more negatively charged ligands are exposed, attracting more metal cations to the adsorbent. Furthermore, at higher pH levels, metal binding to the adsorbent surface decreases due to reduced metal solubility, leading to increased precipitation (Mahdi et al., 2023; Bansal et al., 2009).

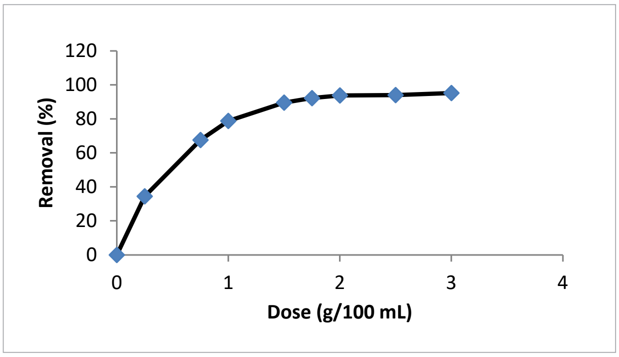
**Fig. 4.** *Impact of pH on nickel removal percentage with a contact time of 60 minutes and biosorbent mass of 2 g in 100 mL*




## Impact of biosorbent mass

The dosage of the biomaterial is a critical factor in determining the adsorption capacity of the biomaterial at a specific initial mass. The effect of this parameter on nickel removal was evaluated by varying the biosorbent mass between 0.25 g and 3 g in 100 mL of simulated wastewater, with a contact time of 60 minutes at room temperature. Each batch test began with an initial nickel concentration of 100 mg/L. *Fig. 5* illustrates the trend of nickel removal in relation to the varying mass of the adsorbent.

**Fig. 5.** *Impact of biosorbent mass on the removal process with a contact time of 60 minutes and pH of 6.0*




It was noted that by increasing the mass of the adsorbent, the removal percentage of Ni (II) was also increased. Increasing the mass of the adsorbent resulted in greater available surface area for adsorption and, as a consequence, enhancing the metal removal percentage (Mahdi et al., 2023; Bansal et al., 2009). The highest removal of Ni (II), 93.67%, was achieved at a concentration of 2 g/100 ml of adsorbent with a contact time of 60 minutes at room temperature.

## Impact of contact time

The concentration of nickel (II) ions after the adsorption process was significantly reduced by extending the contact time. *Fig. 6* shows that the nickel removal percentage increased from 86.75% to 95% when the contact time was extended from 30 to 120 minutes at room temperature. Equilibrium of the adsorption process was reached at 90 minutes, indicating the maximum removal percentage. This could be attributed to the abundance of available empty adsorption sites. However, the depletion of these sites and the reduced repulsive force between nickel ions and the solution eventually diminished nickel adsorption (Ali, 2017; Saravanane et al., 2002).

**Fig. 6.** *Impact of contact time on removal process with a pH of 6 and biosorbent mass of 2 g in 100 mL*

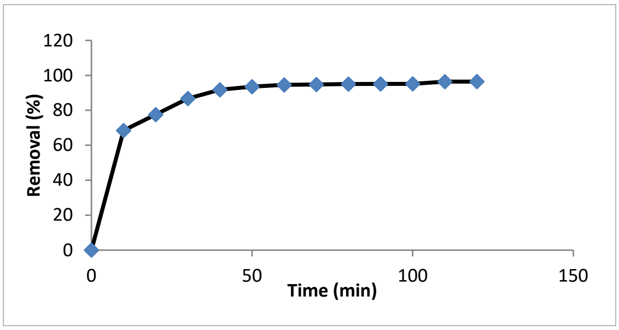
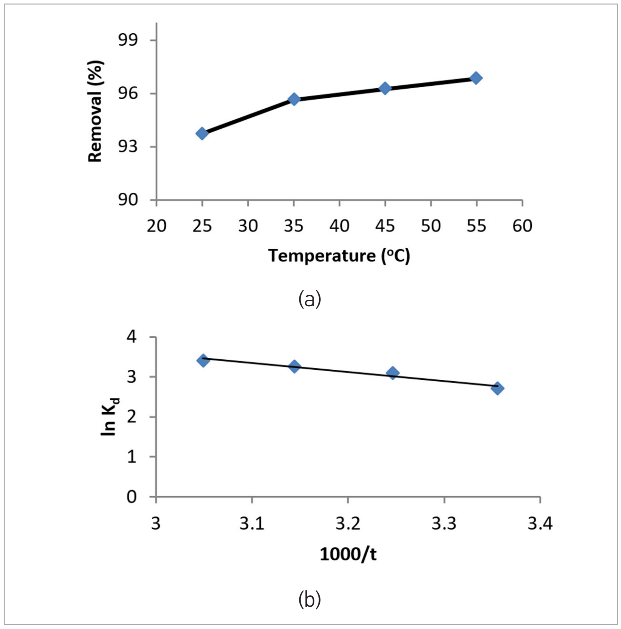



**Fig. 7.** *Impact of increasing temperature on the removal process (a); the distribution coefficients at different temperatures (b) (contact time = 60 minutes; pH = 6; biosorbent mass = 2 g in 100 mL)*




## Thermodynamic parameters and temperature impacts

To determine whether the adsorption reaction is endothermic or exothermic, one must consider the effects of temperature variations (15°C, 25°C, 35°C, and 45°C) as well as thermodynamic parameters such as (ΔH°), (ΔS°), (ΔG°). The thermodynamic parameters were calculated using Eqs. (5) and (6) (Schiewer and Volesky, 1997).

$$lnK_d = \left(\frac{\Delta S^\circ}{R}\right) - \left(\frac{\Delta H^\circ}{RT}\right) \quad (5)$$

$$\Delta G^\circ = \Delta H^\circ - \Delta S^\circ T \quad (6)$$

The gas constant (R) is 8.314 J/mol.K, and the Gibbs free energy change is denoted by ΔG°. The distribution coefficient is denoted by $K_d$, the enthalpy by ΔH° (in J/mol), the entropy by ΔS° (in J/mol.K), and the temperature by T in Kelvin.

The findings in *Table 1* and *Fig. 7* demonstrate that the adsorption process is typically endothermic, meaning that as temperature rises, the adsorption process is enhanced, resulting in more nickel (II) ions attaching to the surface of the adsorbent. A maximum removal percentage of nickel ions (96.85%) was achieved at a temperature of 55°C. The findings show that the ΔG° values are positive and increase in absolute magnitude with temperature. This indicates a spontaneous adsorption process and suggests that higher temperatures enhance the adsorption of nickel ions onto lemon peel.

## Biosorption isotherm

Two equilibrium adsorption isotherms (Langmuir and Freundlich) were used to show the relationship between the nickel ion concentration remaining at equilibrium, Ce (mg/L) and the amount of nickel adsorbed per unit weight of adsorbent, x/m (mg/g). One of the first theoretical approaches to nonlinear sorption is the Langmuir model, which assumes monolayer sorption, with no interactions between the adsorbed molecules,

**Table 1.** *The thermodynamic parameters and the distribution coefficients for the removal process at different temperatures*

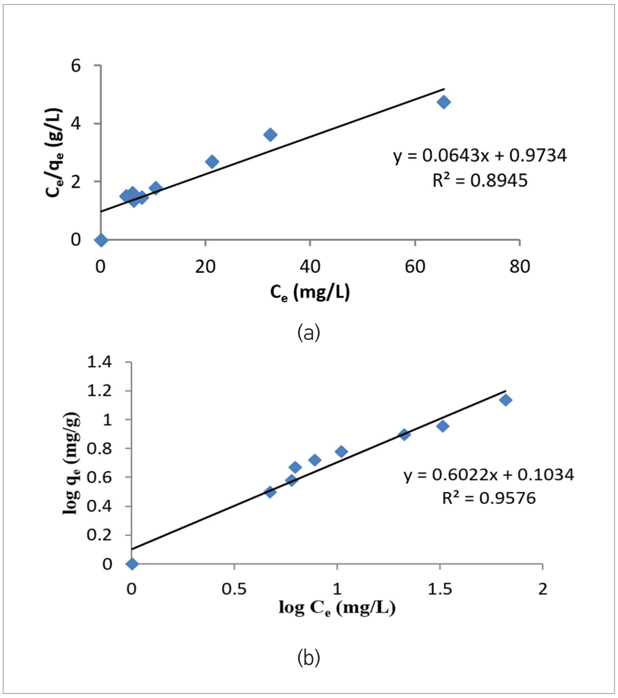
| Metal | $K_d$ | | | | $R^2$ | Δ*H*° (J/mol) | Δ*S*° (J/mol·K) |
|---|---|---|---|---|---|---|---|
| Ni (II) | 289 | 308 | 318 | 328 | 0.9617 | 18.865 | −86.266 |
| | 14.992 | 21.988 | 25.724 | 30.726 | | | |
| | Δ*G*° | | | | | | |
| | 25.726 | 26.889 | 27.451 | 28.314 | | | |

leading to uptake on a homogenous surface. Eq. (7) represents the Langmuir adsorption isotherm in a linear form (Albazzaz et al., 2024; Bavi, 2023; Schiewer and Volesky, 1997):

$$\frac{Ce}{qe} = \frac{1}{bqm} + \frac{Ce}{qm} \quad (7)$$

In Eq. (7), the variables Ce, qe, b, and qm denote the solute concentration in the solution at equilibrium (mg/L), the solute adsorbed per unit mass of biomass (mg/g), the Langmuir constant (L/mg), and the maximum adsorption capacity for monolayer coverage (mg/g), respectively. The slope and the intercept of the Langmuir plot were used to calculate the monolayer capacity (b and qm) and the equilibrium constant for the adsorbate-adsorbent (*Fig. 8*).

**Fig. 8.** *Langmuir (a) and Freundlich (b) adsorption isotherms (contact time = 60 minutes; pH = 6; biosorbent mass = 2 g in 100 mL)*




The Freundlich model is suitable for cases where non-ideal sorption onto heterogeneous surfaces leads to multilayer sorption. For the adsorption of nickel, the linear Freundlich isotherm was applied. It is expressed as follows (Albazzaz et al., 2024; Schiewer and Volesky, 1997):

$$\log q_e = \log k + \frac{1}{n} \log C_e \quad (8)$$

where K is Freundlich capacity constant (mg/g) which indicates the adsorbent's relative adsorption capability. The constant 1/n represents the Freundlich adsorption intensity. The constants K characterizes the strength of the adsorption process, and the removal efficiency of the adsorbent increases with higher K values. The constant n is associated with the energetic heterogeneity of the adsorbent surface. Isotherms with 1/n values less than one are preferred. However, linear isotherms may be desirable as they result in higher solid-phase concentrations. However, a linear isotherm is obtained when the 1/n value is 1, a scenario commonly associated with natural sorbents (Schiewer and Volesky, 1997). Linear Freundlich plots are obtained by plotting log qe against log Ce, which can be used to estimate adsorption coefficients (*Fig. 8*). *Table 2* lists all constants determined for the Freundlich and Langmuir isotherms.

Based on the correlation coefficient ($R^2$) mentioned in *Table 2* and displayed in *Fig. 8*, the data obtained in this study are best represented by the Freundlich isotherm.

## Kinetic outcomes

The rate at which heavy metal ions are absorbed onto the surface of the adsorbent can be evaluated by analyzing adsorption kinetics. This rate determines the duration that these ions remain at the solid-liquid interface. Therefore, it is crucial to assess the time-dependency of these systems for different pollutant removal processes, thus determining the efficiency and

**Table 2.** *The biosorption isotherm parameters for nickel (II) adsorption onto lemon peel*

| Model of Langmuir | Ni (II) | Model of Freundlich | Ni (II) |
|---|---|---|---|
| $R^2$ | 0.8945 | $R^2$ | 0.9576 |
| $q_m$ (mg/g) | 15.552 | 1/n | 0.6022 |
| b (1/mg) | 0.0626 | K (mg/g)(1/mg)$^{1/n}$ | 1.2688 |

effectiveness of the adsorbent over time. In addition, this provides insights into the time required for significant initial adsorption and suggests a potential diffusion regulation mechanism as the adsorbate ion migrates from the primary solution to the adsorbent interface (Yasmin et al., 2015). Ion removal happens more quickly during the initial phase of the adsorption process. The adsorbent's initial surface area accessibility may account for the quicker initial rate. The adsorption kinetics are influenced by the adsorbent's effectiveness in capturing targeted ions, which is influenced by its surface area as well as the nature and density of its active sites or surface groups. Eqs. (9) and (10), representing the pseudo-first order and pseudo-second order models, illustrate the kinetics of the adsorption process (Schiewer and Volesky, 1997):

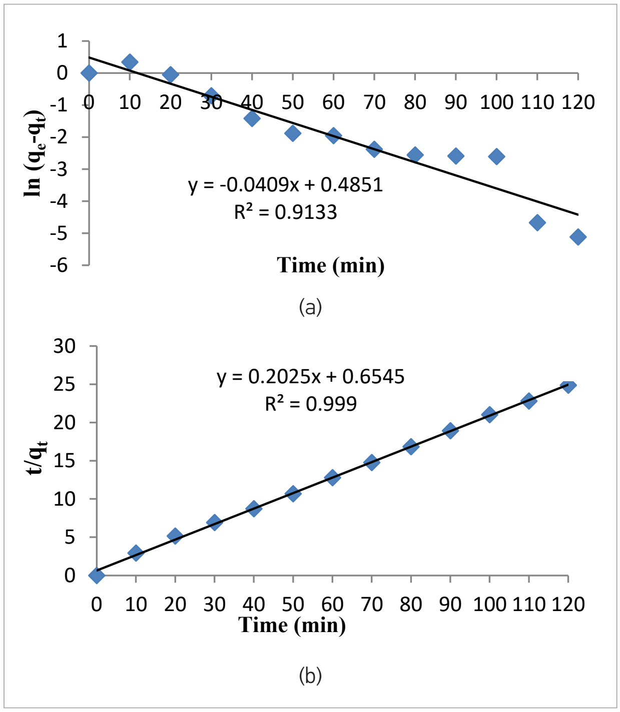
$$\ln (q_{eq} - q_t) = \ln q_e - k_1 t \quad (9)$$

$$\frac{t}{q_t} = \left(\frac{1}{k_2\, q_{eq}^2} + \frac{t}{q_{eq}}\right) \quad (10)$$

where $q_{eq}$ represents the mass of adsorbate adsorbed at equilibrium (mg/g); qt denotes the mass of adsorbate adsorbed at time t (mg/g); $k_1$ is pseudo-first-order adsorption constant (1/min); and $k_2$ is pseudo-second-order adsorption constant (g/mg·h). The pseudo-first-order rate constants ($k_1$) and $q_{eq}$ were calculated from the slope and y-intercept of the plot, as shown in *Fig. 9(a)*. Additionally, the pseudo-second-order constants were indirectly obtained from the slope and y-intercept of the plot, as shown in *Fig. 9(b)*.

A comparison between the two models revealed that the experimental data were best represented by the pseudo-second-order model, as determined by the correlation coefficient ($R^2$) values. The computed values of $q_e$ from the second-order kinetic model aligned closely with the experimental results, as demonstrated in *Table 3*.

**Fig. 9.** *Plot of nickel (II) adsorption using kinetic models on lemon peel. Models (a) and (b) are pseudo-first-order and pseudo-second-order models, respectively*




## Conclusions and Recommendations

This study found that inexpensive lemon peels are a good biosorbent for the batch removal of nickel (II) ions from metal-contaminated water. Through batch-mode experiments, the optimal values for pH, contact time, biosorbent dosage, and temperature were identified as key conditions for nickel (II) elimination. A pH of 6.0 was found to be optimal. In addition, the nickel removal percentage increased from 86.75% to 95% when the contact time was extended from 30 to 120 minutes. Moreover, the highest removal percentage of nickel (II), 93.67%, was achieved at an adsorbent

**Table 3.** *Evaluation of the reaction kinetics for both performed and estimated values of the pseudo models*

| Metal | $q_e$ performed (mg/g) | Pseudo-first order | | | Pseudo-second order | | |
|---|---|---|---|---|---|---|---|
| | | $K_1$ (1/min) | $q_e$ estimated (mg/g) | $R^2$ | $K_2$ (g/mg·min) | $q_e$ estimated (mg/g) | $R^2$ |
| Ni (ii) | 4.830 | -0.0409 | 1.624 | 0.9133 | 37.28 | 4.938 | 0.999 |

concentration of 2 g/100 mL and a contact time of 60 minutes. Furthermore, the findings showed that the ΔG° values were positive and increased in absolute magnitude with temperature. The data showed a good fit to the Freundlich model, indicating multilayer biosorption of nickel (II). Lemon peel biosorption presents an attractive treatment option for nickel (II)-contaminated water due to its high biosorption intensity, low cost, and environmental benefits associated with utilizing agricultural waste. Finally, the following recommendations are proposed: (i) improving the surface of the adsorbent to enhance efficiency and (ii) conducting future research to explore different configurations for column studies.

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