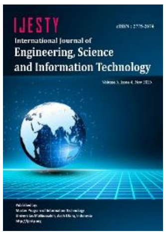
International Journal of Engineering, Science and Information Technology
Volume 5, No. 4 (2025) pp. 670-678
eISSN: 2775-2674
Website: http://ijesty.org/index.php/ijesty
DOI: https://doi.org/10.52088/ijesty.v5i4.1773
Research Paper, Short Communication, Review, Technical Paper



Biosorption of Ni(II) Ions from Aqueous Solution Using Immobilised Cells of Bacillus cereus

Khairunnisa*, Ahmad Moh.Nur, Dian Febrianti Pisceselia, Aulia Almag Fira, Putri Aldeani

Department of Chemical Engineering, Faculty of Engineering, Universitas Mulawarman, Samarinda, Indonesia

**Corresponding author Email:khairunnisa@ft.unmul.ac.id*

The manuscript was received on 2 May 2025, revised on 28 June 2025, and accepted on 26 October 2025, date of publication 29 December 2025

Abstract

In the present study, immobilised Bacillus cereus cells were used as a biosorbent for the removal of Ni^{2+} ions from aqueous solution. Bacillus cereus was immobilised with 3% sodium alginate and 2% $CaCl_2$. The adsorption studies of bacteria were investigated in batch mode. Optimum biosorption conditions were determined as a function of pH, biosorbent dose, Ni2+ ion concentration, and contact time. The removal of Ni^{2+} ions increases with increased dose of biosorbent, while the adsorption capacity decreases with increasing dose of biosorbent. The equilibrium adsorption data were analysed using the Langmuir and the Freundlich isotherm models. The regression coefficient (R2) for the Langmuir isotherm was 0.9822 at a contact time of 60 minutes and pH 6. The maximum monolayer adsorption capacity (qe) of the biosorbent, as obtained from the Langmuir adsorption isotherm, was found to be 57.80 mg/g with the Langmuir adsorption constant (k_L) 0,086 L/mg. RL values range from 0 to 1, as shown, supporting the previous observation that the Langmuir isotherm was favourable for Ni2+ ion adsorption. The adsorption kinetics were analysed using the pseudo-first-order and pseudo-second-order models. Kinetics of Adsorption followed pseudo-second order with a regression coefficient of pseudo-second order of R2 0.98, the coefficient of rate constant for pseudo-second order (k_2) obtained 0.004 g/mg.min, pointing out that the adsorption mechanism is chemosorption or ion exchange. FTIR spectrum of biosorbent revealed the presence of OH, NH, C-H, C=O and COO-. SEM-EDX was used to analyse the surface morphology and texture of the biosorbent.

Keywords: *Bacillus Cereus, Immobilised Cells, Biosorption, Nickel (II), Adsorption Isotherms, Kinetics.*

1. Introduction

World population growth is very rapid, and the rapid development of industry has led to more toxic waste that harms the environment. This waste, which later accumulated and polluted the environment in amounts difficult to control precisely. The most polluting substance, dominated by heavy metal waste, is Nickel.

Pollution by Nickel usually comes from several industrial processes, such as electroplating, plastics manufacturing, Nickel–cadmium batteries, fertilisers, pigments, mining, and metallurgy [1][2][3].

Heavy metals, including Nickel, cannot be destroyed or degraded. Heavy metals in waste are present in various forms, including undissolved, dissolved, reduced, oxidised, and complexed. According to UUD No. 101 year 2014 about B3, sewage treatment is partly included in the category of dangerous waste, and toxic, acidic mine water containing heavy metals should be managed in accordance with the procedures for processing B3 sewage. The main techniques used for treating Ni2+-bearing waste streams include conventional methods such as chemical precipitation, ion exchange, activated carbon adsorption, and membrane separation, each with limitations for removing heavy metals from wastewater. They become inefficient and expensive, especially when the heavy metal concentration is less than 100 ppm [4][5]. A recently developed process, bioadsorption, is now attracting the attention of researchers for the eco-friendly removal of heavy metals from wastewater [6]. The process is based on the ability of certain biological materials to adsorb inorganic and organic compounds from their solutions [7]. However, we used bacterial biomass as biosorbents, taking advantage of their high surface area and the high content of potentially active sites in their cell walls [8].

In recent years, the immobilisation of biomass on natural and synthetic polymeric supports has received increasing attention for contaminant treatment, as it improves biosorption rates, microbial performance, and biosorbent stability compared with the native form [9]. Additionally, it is pertinent to note that entrapment of biomass in an ideal carrier makes it a potential biosorbent due to its biodegradability, reduced toxicity, improved mechanical strength, and easy separation of solid biomass from the bulk liquid, with the added benefit of auxiliary reuse [10]. In this respect, alginate comprising b-d-mannuronic acid and a-l-guluronic acid has proved its worth as a primary host matrix for environmental remediation [11].

In the present study, the potential of immobilised Bacillus cereus for the removal of Ni2+ ions from aqueous solutions and the effects of various parameters, such as the contact time of biosorbent and sorbents, pH of the metal solutions, biosorbent dose, and initial metal ion concentration, have been investigated. Equilibrium modelling of biosorption was carried out using the Langmuir and the Freundlich adsorption models. In addition, the biosorption was modelled using the Lagergren pseudo-first-order and second-order kinetic models to elucidate the kinetic behaviour. Furthermore, the adsorption phenomena were investigated using mechanistic probing via Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM) equipped with energy-dispersive X-ray spectroscopy (EDXA).

2. Methods

2.1. Chemicals

Nickel chloride($NiCl_2.6H_2O$), HCl, NaOH, Sodium Alginate, $CaCl_2$, Bacillus cereus, NB medium, Aquadest. glucose.

2.2. Bacteria and Growth Conditions

Bacillus cereus purchased from the Microbiology Laboratory, Institut Teknologi Sepuluh Nopember, Surabaya. The media used for bacterial growth were Nutrient Broth (NB) and glucose. For biomass production, the bacteria were cultivated on a rotary shaker at 150 rpm and 280 °C for 32 hr in a 250 ml Erlenmeyer flask containing 200 ml of NB medium.

2.3. Biomass immobilisations

After 32 hr of incubation, the biomass was obtained by centrifugation at 8000 rpm for 10 min and washed with sterile water. Immobilised biosorbents were prepared as alginate beads by ionic polymerisation in calcium chloride solution, as described by Naskar (2017). 4,5% (w/v) sodium alginate solution was mixed thoroughly with bacterial cells at 1,5% (w/v) in a ratio to attain a final alginate concentration of 3%.

The mixture was then dropped into a 2% Calcium chloride solution using a biuret. The drops of sodium alginate solution gelled into ±3 mm-diameter beads upon contact with calcium chloride solution. Ca-alginate gel-immobilised Bacillus cereus cell particles were stored in 2% calcium chloride solution at 40 °C for at least 24 hr to complete gelation. The beads were rinsed in Aquadest and dried in an oven for 24 hr at 600 °C. Then, dried, immobilised Bacillus cereus cells were ground in a mortar with a pestle and stored in a desiccator for future use.

2.4. Preparation of Metal Solution

All chemicals used in the present study were analytical grade. Stock metal solution Ni^{2+} (1000 mg/L) was prepared by separately dissolving $NiCl_2$.($6H_2O$ in Aquadest. For experiments with various metal concentrations, the stock solutions were diluted further with Aquadest. The pH value of the test metal solution was adjusted to the desired value with 0,1 M HCl and 0,1 M NaOH.

2.5. Biosorption Experiments

The biosorption of Ni^{2+} from aqueous solutions was carried out in a batch system. 150 mg of dried immobilised Bacillus cereus was added to 250 mL Erlenmeyer flasks containing 150 mL of a 35 ppm metal solution, and the flasks were agitated in an orbital shaker for 60 min at 150 rpm and 30^0 °C. The effects of initial pH (3-8), contact time (5-240 min), initial metal ion concentration (25-200 ppm), and biosorbent mass (150 mg-500 mg) on metal biosorption were studied. After each experiment, the mixture was separated, and the metal ion concentration in the supernatant was determined. All biosorption experiments were done in duplicate, and the mean values were reported. The amount of adsorbed metal ions is estimated as the amount of metal (mg) per unit of biosorbent dry weight (g) using the following equation :

$$q = \frac{V\,(C_i - C_f)}{M} \tag{1}$$

Where V is the volume of metal solution (L), Ci is the initial metal concentration (mg/L), Cf is the final/residual metal concentration (mg/L), q is the adsorption capacity (mg/g), and M is the amount of biosorbent (g). The percentage biosorption of the metal ion was calculated as follows :

$$\%\ \text{Biosorption} = \left(\frac{C_i - C_f}{Ci}\right) \times 100 \tag{2}$$

2.6. Analysis of Metal Ions

The concentration of Ni^{2+} ions in the supernatant of the biosorption medium was determined by AAS (Atomic Absorption Spectroscopy).

2.7. Characterisation of The Immobilized Bacillus cereus

The surface morphology of the biosorbent before and after metal ion adsorption was analyzed through SEM FEI-INSPECT S50. Elemental analysis of the Ni2+ ion, along with other elements, was also obtained using an EDX spectrometer system equipped with a SEM. Samples were coated with Gold-Palladium before SEM-EDX analysis. The infrared (IR) spectra of the biosorbent before and after contact with Ni2+ were recorded using a Thermo Scientific Nicolet spectrometer.

2.8. Biosorption Ispthems

Several mathematical models have been developed to quantitatively express the relationship between Adsorption and the residual solute concentration. The most widely used models are the Langmuir and the Freundlich adsorption isotherms. To determine the adsorptive capacity of immobilized Bacillus cereus for Ni^{2+} ions, the initial concentration was varied from 25 to 200 mg/L. The biosorbent was constant at 0,15 g, the 150 mL solution was optimal, and the time was optimal.

Langmuir equation is based on the assumptions that maximum Adsorption corresponds to a saturated monolayer of adsorbate molecules on the adsorbent surface with a uniform distribution of energy levels, The Langmuir isotherm is defined as[13]:

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e} \quad (3)$$

and in linearised form is

$$\frac{1}{q_e} = \frac{1}{q_m K_L} \frac{1}{C_e} + \frac{1}{q_m} \quad (4)$$

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{1}{q_m} \times C_e \quad (5)$$

Where qm and KL are Langmuir constants related to the sorption capacity, and sorption energy, respectively, Ce is the equilibrium concentration in mg/L, and qe is the amount of adsorbate adsorbed per unit weight of Adsorption (mg/g). When C_e/q_e is plotted against C_e, a straight line with slope 1/(q_m K_L) is obtained and intercept is corresponding 1/q_m . Also, q_m and KL were determined. The essential characteristics of Langmuir dimensionless constant separation factor equlibrium parameter, RL, which is defined by the following equation :

$$R_L = \frac{1}{1 + K_L \times C_0} \quad (6)$$

The Freundlich adsorption isotherm, one of the most widely used mathematical descriptions, provides an expression that accounts for surface heterogeneity and the exponential distribution of active sites and their energies [14]. The Freundlich isotherm is defined as :

$$q_e = K C_e^{1/n} \quad 7)$$

and in linearised form it is expressed as :

$$\mathrm{Ln}\ q_e = \ln K_F + \left(\frac{1}{n}\right) \ln C_e \quad (8)$$

Where Ce is the equilibrium concentration in mg/L, q_e is the amount of adsorbate adsorbed per unit weight of adsorbent (mg/g). KF is an empirical constant that provides an indication of the intensity of Adsorption and “n” Freundlich adsorption constant. When the values of ln Ce are plotted against the value of ln q_e, the adsorption constants (KF and n) were obtained.

2.9. Kinetics of Adsorption

Adsorption kinetics describes the rate of the solute uptake at the solid-solution interface and provides valuable information about the reaction pathways and mechanisms. The Kinetics of Ni2+ ion adsorption on immobilized Bacillus cereus are analyzed using simulations of two kinetic models: pseudo-first-order and pseudo-second-order.

Pseudo first-order model

The rate of the adsorptive interaction can be investigated by using the simple Lagergren equation [14]. This model describes the rate of Adsorption to be proportional to the number of unoccupied sites by the solutes :

$$\log (qe - qt) = \log qe - k1t \quad (9)$$

where qe and qt are the amounts of Ni^{2+} adsorbed (mg/g) atequilibrium and at time t (min), respectively and k1 is the pseudo-first-order adsorption rate constant (L/min).

Pseudo second order model

Pseudo-second-order model data are applied to the Ho and McKay’s pseudo-second order chemisorption kinetic rate equation which is expressed as [15].

$$\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad 10)$$

3. Results and Discussion

3.1 Characteristics of the immobilised Bacillus cereus

3.1.1. Functional Characteristic

Fourier transform infrared analysis (FTIR) is one of the most powerful tools for identifying the characteristic functional groups present in bacterial cell walls. FTIR spectra of before and after Ni^{2+} biosorption are shown in **Figure 1** and were compared in the range of 400–4000 cm−1 to determine the interaction of the metal ions and to identify functional groups which are responsible for the Ni^{2+} biosorption process.

The surface of the biosorbent was found to contain essential functional groups. The vibration frequencies and their corresponding groups are presented in **Table 1.**

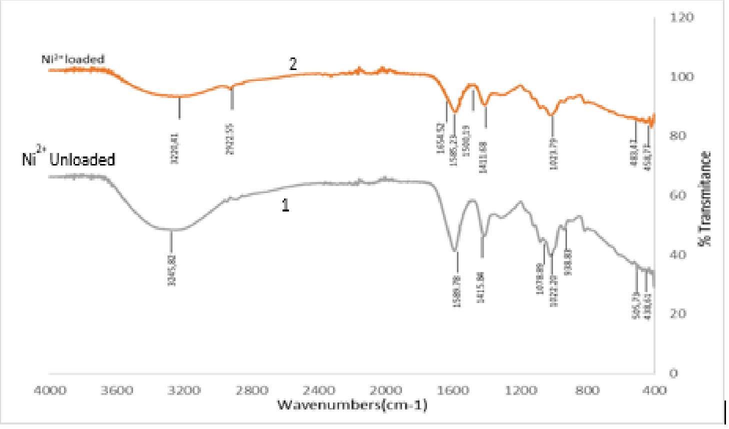


Fig 1. FT-IR spectra of (1) Ni^{2+} unloaded and (2) Ni^{2+} loaded

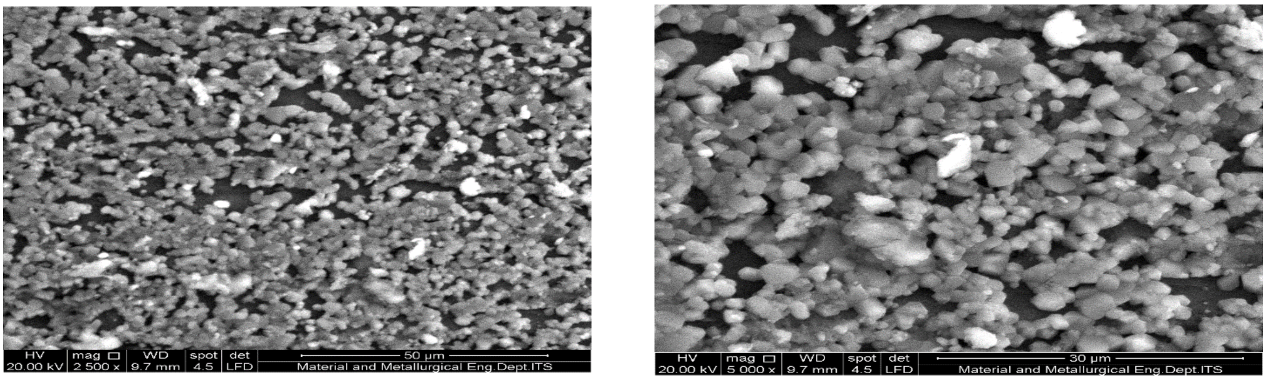
Table 1. Main Functional groups on the surface of immobilised Bacillus cereus as observed from FTIR spectroscopy.

FTIR Spectra Range (cm-1)	Wavenumber range (cm-1)		Functional group assignment
	Before Ni biosorption	After Ni biosorption	
3600-3100	3245,82	3220,41	OH, NH
3000-2800	-	2922,55	C-H
1730-1650	-	1654,52	C=O
1600-1500	-	1500,19	COO-
1500-1440	1415,64	1411,68	H-C-H
1300-1000	1022,2	1023,79	C-O
1300-1100	1078,88	1023,79	$-SO_3$

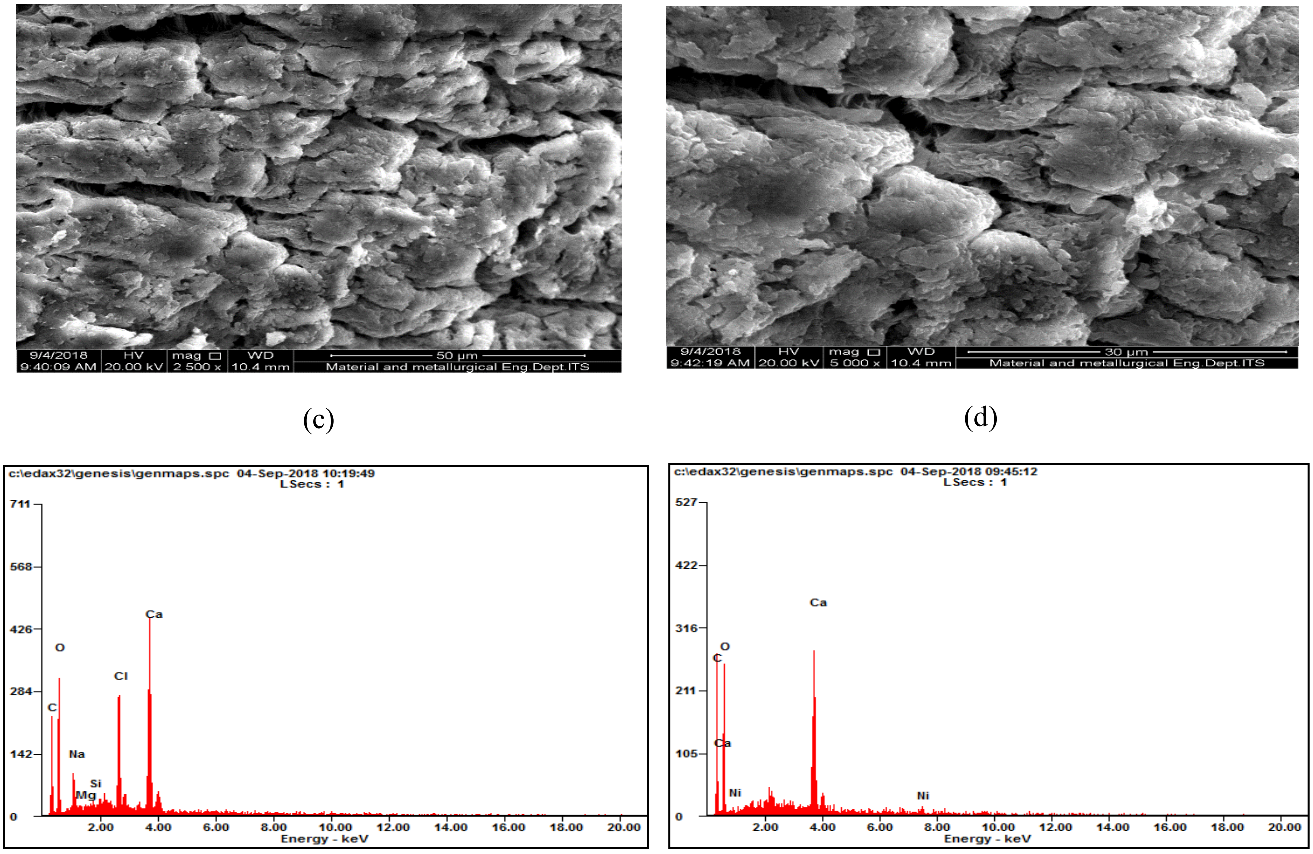
The analysis of the surface-immobilised Bacillus cereus in Table 1 revealed the presence of essential functional groups. After and before exposure of immobilised Bacillus cereus to Ni2+ ions, the wavenumbers of the FTIR spectra for each chemical functional group shifted, indicating a chemical reaction between the functional groups and Ni^{2+} ions. The identified functional chemical groups were responsible for Ni2+ ion selectivity. In addition, the electronegativity of chemical functional groups.

3.1.2. Morphology Characteristic

The scanning electron microscopy equipped with energy-dispersive X-ray analysis (SEM-EDXA) (Figures 2a and 2c) are SEM micrographs of the before and after Ni2+ ion biosorption, respectively, and Figures 2e and 2f are the corresponding EDX spectra. The biosorbent before contact with Ni2+ ions has an amorphous structure with no definable surface. Significant textural change towards the compactness and coherency in the surface morphology of the metal-laden biosorbent is observed compared to that of the biosorbent before contacting Ni^{2+} ions. Further, morphological alterations are more clearly depicted in the higher-magnification SEM images (Fig. 2b and 2d). EDXA Figure 2e and 2f spectra record the signals of carbon, oxygen, calcium, sodium, silica, magnesium and chloride emitting from the polysaccharides and proteins present on the cell wall of the biomass surface. Additional signals of Nickel (II) noted in the EDXA profile indicate its presence due to Adsorption on the surface biosorbent. Additional signals of Nickel after Adsorption on immobilised biomass indicated the incorporation of metal ions on the biomass surface (Figure 3f). Besides, it was observed that, due to metal ion adsorption by the immobilised biomass, the sodium peaks disappeared, with concomitant appearance of the Ni peaks. Thus, the adsorption process was considered to be an ion-exchange process, along with complexation or other physical interactions.



(a) (b)



(c) (d)

(e) (f)

Fig 2. SEM images of immobilised bead before (a,b) and after Ni (II) ions sorption (c,d) with corresponding EDXA spectra before (e) and after (f)

3.2. Effect of pH on Metal Biosorption

pH of the aqueous solution plays a vital role in the biosorption process because it affects the chemistry of the metals and the surface charge and ionisation of the functional groups on the bacterial cell wall during the reaction [16]. The effect of pH on Ni2+ biosorption was investigated over the pH range 3-8 at a metal ion concentration of 35 mg·L-1. From the results illustrated in **Figure 3**, it was found that the biosorption capacity of Ni2+ ions was lower at lower pH and increased as the pH of the solution increased. The optimum pH for Ni2+ biosorption was 6, at which the biosorption capacity was 24,083 mg/g. An increase or decrease in pH from these optimum values resulted in a reduction in biosorption of these metal ions. At low pH values, protons in solution compete effectively with metals in binding to functional groups [17].

The decrease in biosorption of Ni^{2+} ions above pH 6 is due to precipitation of metals as insoluble hydroxides or hydrated oxides [18]. The effect of pH is similar to that of [17] using biomass of Eupenicillium [7] using immobilised Bacillus cereus.

3.3. Effect of Contact Time

The effect of contact time (15 to 240 min) on the equilibrium uptake of Ni^{2+} ions onto immobilised Bacillus cereus for an initial metal ion concentration of 35 mg·L−1 is shown in **Figure 4**. The biosorption capacity increased with increasing contact time, and a large amount of metal ions was removed within 60 min, with biosorption values reaching 15,05 mg/g. After these equilibrium periods, Ni^{2+} ion biosorption, the amount of adsorbed metal ions did not change significantly with contact time, which may be due to the presence of more binding sites for metal ion adsorption. The slow metal removal in subsequent stages may be due to the occupation/saturation of these binding sites with Ni^{2+} ions [19].

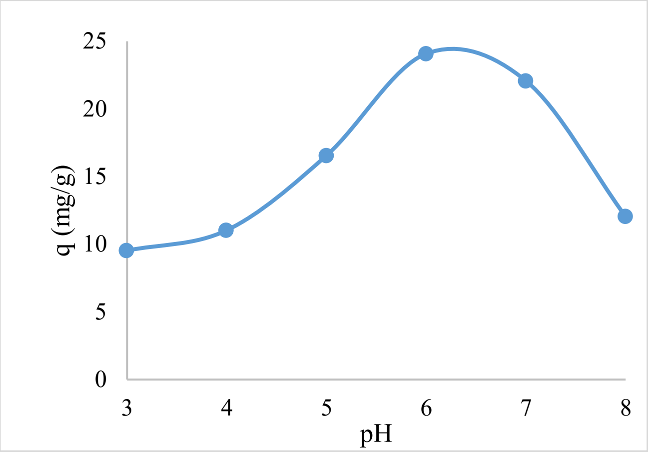


Fig 3. Ni^{2+} Biosorption (mg/g) by immobilised Bacillus cereus at different pH values

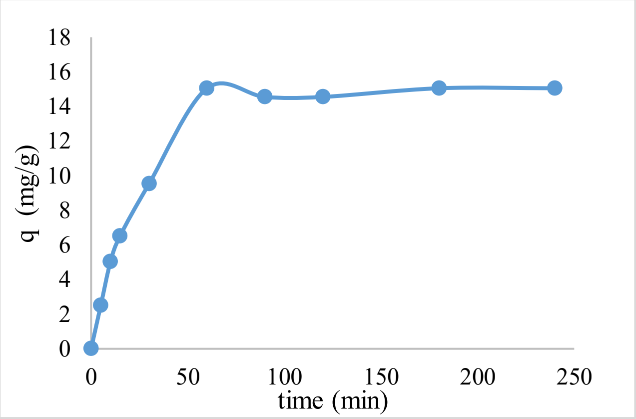


Fig 4. Ni^{2+} Biosorption (mg/g) by immobilised Bacillus cereus at different time intervals (min)

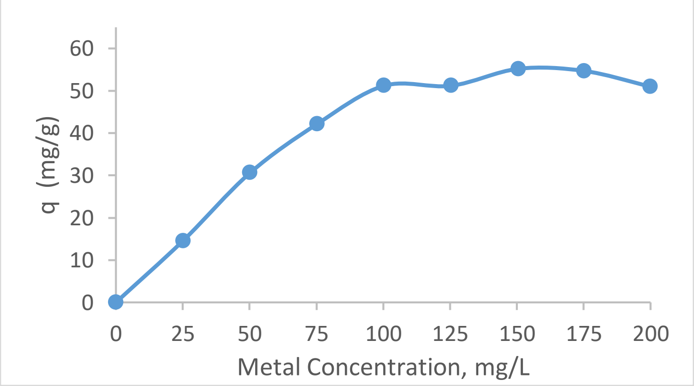


Fig 5. Ni^{2+} Biosorption (mg/g) by immobilised Bacillus cereus at different metal concentrations (mg/L)

3.4. Effect of Initial Metal Ion Concentration

The initial metal ion concentration remarkably influenced the equilibrium metal uptake and biosorption yield. The effect of the initial metal (Ni2+ ion) concentration was investigated in the range of 25 - 200 mg/L under the determined optimum pH and contact time, as shown in **Figure 5**.

It can be observed that the adsorption capacity of the sorbents increases with increasing initial metal concentration from 14,55 mg/g to 55,19 mg/g. This is because the initial concentration contributes to the driving force to overcome mass transfer resistances for ions between the sorbent and bulk fluid phases. Higher initial concentrations increase the mass-transfer driving force, thereby increasing uptake. In addition, increasing the initial metal ion concentration increases the number of collisions between metal ions and the sorbent, thereby enhancing sorption [20].

3.5. Effect of Biosorbent Dose on Adsorption

To get the optimal biosorbent dose in Ni^{2+} biosorption, different adsorbent doses from 0,15-0,5g were added to 150 mL aqueous solution with a concentration of 100 mg/L under the determined optimum pH values and contact time. We noted an increase in percentage removal from 44% to 90,5% as the dose increased from 0,15 to 0,5 g, but the adsorption capacity decreased, as shown in **Figure 6**. The increase in percentage removal with increasing adsorbent dose is due to the increased availability of adsorption sites. However, the decrease in adsorption capacity can be explained by the fact that more sites remain unsaturated as the adsorbent increases [21].

3.6. Biosorption Isotherms

A biosorption isotherm provides a relationship between the concentration of metal in solution and the amount of metal adsorbed on the biosorbent at equilibrium. The Ni2+ biosorption on immobilised Bacillus cereus was modelled using the Langmuir and the Freundlich adsorption isotherms. The linearised forms of the Langmuir isotherm (Equation 5) and the Freundlich isotherm (Equation 8) were used to analyse and fit the data to these models. The Langmuir constants (qmax and KL) and their correlation coefficients (R2), and the Freundlich constants (Kf and n) and their correlation coefficients (R2) were calculated from the plots in Figure 7, and the results are presented in **Table 2.**

Table 2 shows the calculated values of the Langmuir and the Freundlich models' parameters. The comparison of correlation coefficient (R2) values for the linearised forms of both the Langmuir and the Freundlich models shows that the Langmuir model yields a better fit to the experimental adsorption equilibrium data and is the most appropriate isotherm to describe the equilibrium data for Ni^{2+} ions than the Freundlich model. This suggests the Adsorption of Ni^{2+} ions onto immobilised Bacillus cereus in a monolayer.

The essential characteristics of the Langmuir dimensionless constant separation factor equilibrium parameter (RL) (equation 5). RL value indicates the type of isotherm to be irreversible (RL = 0), favourable (0 < RL< 1), linear (RL = 1) or unfavourable (RL> 1) (Abd El-Latif and El-kady, 2010). In this study, RL values fall between 0 and 1, as shown in Table 2. These values support the previous observation that the Langmuir isotherm was favourable for the Adsorption of Ni2+ ions.

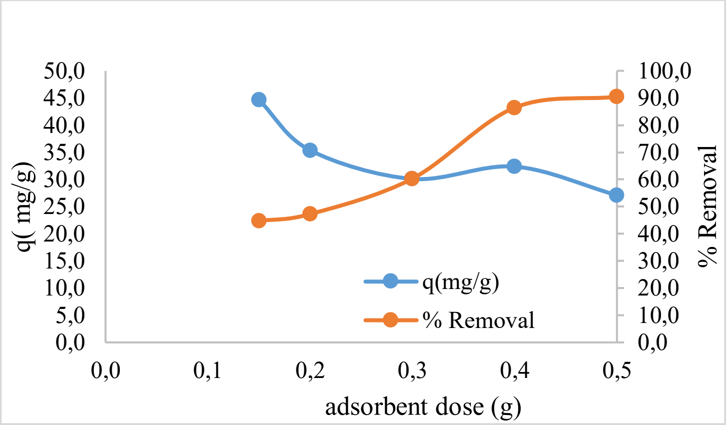
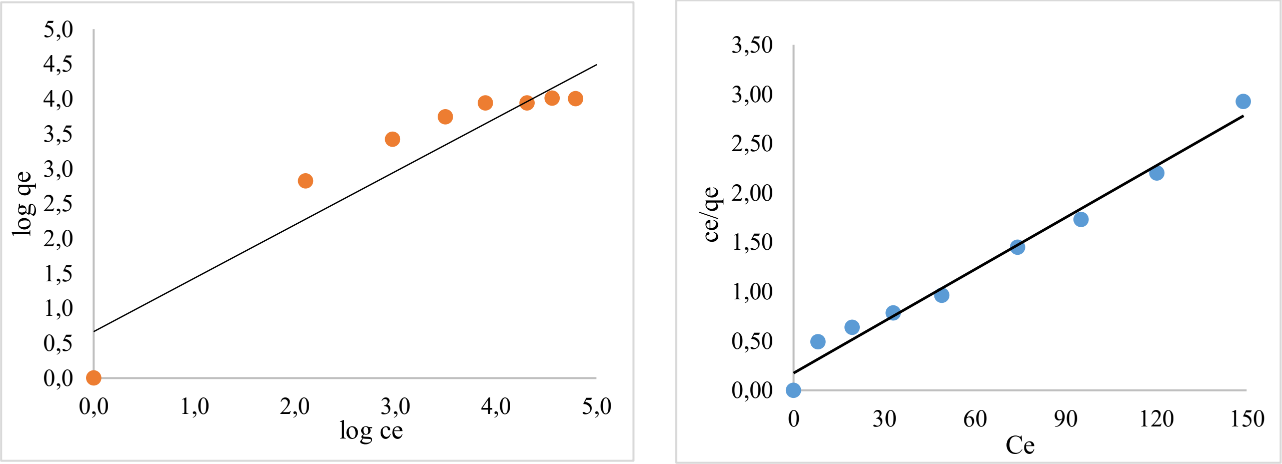


Fig 6. Effect of adsorbent dose on Ni^{2+} biosorption by immobilised Bacillus cereus



(a) (b)

Fig 7. Application of the Isotherm model for Ni^{2+} biosorption by immobilised Bacillus cereus (a) Langmuir isotherm model and (b) the Freundlich isotherm model

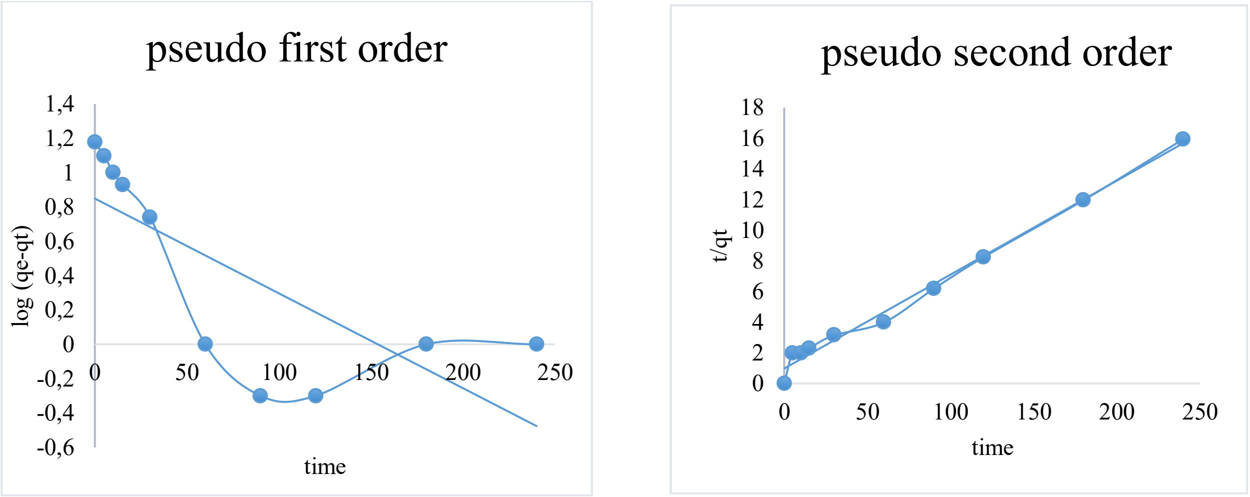
Table 2. Isotherm parameters of models for Ni^{2+} biosorption by immobilised Bacillus cereus

Langmuir Adsorption isotherm				Freundlich Adsorption isotherm		
y = 0,0175x + 0,1745				y = 0,7646x + 0,6659		
qm (mg/g)	KL (L/mg)	R2	RL	n	KF	R2
57,80	0,086	0,9822	0,08-0,2	1,14	1,51	0,8744

3.7. Adsorption Kinetics

The Kinetics of Ni2+ ion adsorption on immobilised Bacillus cereus are analysed using simulations of two kinetic models: pseudo-first-order and pseudo-second-order, described by equations (9) and (10). The linearity plots for pseudo-first-order and pseudo-second-order Kinetics of Ni2+ ions are shown in Figure 8, and the results are presented in **Table 3**.

R2, the correlation coefficient, agrees with experimental data and the model-calculated values. The relatively high R^2 value indicated that the model successfully follows the Kinetics of Ni^{2+} ion adsorption. For the pseudo-first-order kinetic model, the correlation coefficients are lower. The second-order model, as shown in Table 2, appears to be a better-fitting model than the first-order equation because it has a higher R^2. The linear correlation coefficient obtained was $R^2 = 0.998$. As a result, the pseudo-second-order kinetic model was more representative for simulating the kinetic data than the pseudo-first-order kinetic model. The pseudo-second-order kinetic model assumes that the rate-controlling step may be chemisorption involving valency forces through the sharing or exchange of electrons between the adsorbent and the adsorbate [22].



(a) (b)

Fig 8. Application of the Isotherm model for Ni^{2+} biosorption by immobilised Bacillus cereus (a) Langmuir isotherm model and (b) the Freundlich isotherm model

Table 3. Kinetics parameters for Ni^{2+} biosorption by immobilised Bacillus cereus

q exp (mg/g)	Pseudo first-order rate equation			Pseudo-second order rate equation		
	y = 0,0612x + 0,9822			y = -0,0127x + 1,9559		
15,05	qe1 (mg/g)	k1	R^2	qe2	k2	R^2
	16,4	0,004	0,98	7,1	0,005	0,56

4. Conclusion

Immobilised Bacillus cereus in calcium alginate was found to be effective for the removal of Ni^{2+} ions from aqueous solutions. The removal of Ni^{2+} ions increases with increased dose of biosorbent, while the adsorption capacity decreases with increasing dose of biosorbent. The optimum pH for maximum Adsorption of Ni2+ ions was 6, and the equilibrium was reached in 60 minutes. The adsorption equilibrium data fit the Langmuir model, suggesting monolayer coverage. The sorption kinetics followed a pseudo-second-order rate equation—the rate-controlling chemosorption or ion exchange. SEM-EDX results showed that the cell surface of the biosorbent was affected by metal ion interactions. FT-IR analysis revealed that the functional groups of bisorbent were involved in metal biosorption. The overall results showed that the immobilised Bacillus cereus is an effective biosorbent for the removal of Ni^{2+} ions from aqueous solutions.

Acknowledgement

This research was funded by the Faculty of Engineering, Mulawarman University, through the Tropical Engineering Program 2025. The authors express sincere gratitude for the financial support provided.

References

[1] Kefala, M.I., Zouboulis, A.I., Matis, K.A., 1999. Biosorption of cadmium ions by Actinomycetes and separation by flotation. Environmental Pollution 104, 283–293.
[2] Kaewsarn, P., Yu, Q., 2001. Cadmium(II) removal from aqueous solutions by pre-treatedbiomass of marine alga Padina sp.. Environmental Pollution 112, 209–213.
[3] Park, J.K., Jin, Y.B., Chang, H.N., 1999. Reusable biosorbents in capsules from Zoogloea ramigera cells for cadmium removal. Biotechnology and Bioengineering 63, 116–121.
[4] Leusch A, Holan ZR, Volesky B. Biosorption of heavy metals (Cd, Cu, Ni,Pb, Zn) by chemically-reinforced biomass of marine algae. J Chem Technol Biotechnol 1995;62:279–88.
[5] Yan GY, Viraraghavan T. Heavy metal removal in a biosorption column by immobilized M-rouxii biomass. Biores Technol 2001;78: 243– 9.

[6] Ding, Y.; Jing, D.; Gong, H.; Zhou, L.; Yang, X. (2012) Biosorption of aquatic cadmium (II) by unmodified rice straw. Bioresour. Technol., 114: 20–25.

[7] Naskar Animesh and Debabrata Bera.(2017).Mechanistic Exploration of Ni (II) Removal by Immobilized Bacterial Biomass and Interactive Influence of Coexisting Surfactants. Environmental Progress & Sustainable Energy.

[8] Prithviraj, D., Deboleena, K., Neelu, N., Noor, N., Aminur,R., Balasaheb, K., & Abul, M. (2014). Biosorption of Nickel by Lysinibacillus sp. BA2 native to bauxite mine, Ecotoxicology & Environmental Safety, 107, 260–268.

[9] Ting, A.S.Y., Rahman, N.H.A., Isa, M.I.H.M., & Tan, W.S.(2013). Investigating metal removal potential by Effective Microorganisms (EM) in alginate-immobilized and freecell forms, Bioresource Technology, 147, 636– 639.

[10] Banerjee, A., Sarkar, P., & Banerjee, S. (2016). Application of statistical design of experiments for optimization of As (V) biosorption by immobilized bacterial biomass, Ecological Engineering, 86, 13– 23

[11] Shim, J., Lim, J.-M., Shea, P.J., & Oh, B.-T. (2014). Simultaneous removal of phenol, Cu and Cd from water with corn cob silica-alginate beads, Journal of Hazardous Materials, 272, 129– 136.

[12] Langmuir, I., 1918. The Adsorption of gases on plane surfaces of glass, mica andplatinum. J. Am. Chem. Soc. 40, 1361–1403.

[13] Freundlich, H., 1926. Colloid and Capillary Chemistry. Methuen, London, U.K

[14] Lagergren, S., Svenska, B.K., 1898. Zur theorie der sogenannten adsorption geloester stoffe. Vetenskapsakad. Handl. 24, 1–39.

[15] Ho, Y.S., McKay, G., 1999. Pseudo-second order model for sorption processes.Process. Biochem. 34, 451–465.

[16] Tsekova, K., Todorova, D., Dencheva, V. and Ganeva, S. (2010) Biosorption of Copper(II) and Cadmium(II) from Aqueous Solutions by Free and Immobilized Biomass of Aspergillus niger. Bioresource Technology, 101, 1727-1731.

[17] Al-fakih, Abdulkawi Ali. 2015. "Biosorption of Ni^{2+} and Cd^{2+} from Aqueous Solutions Using NaOH-Treated Biomass of Eupenicillium Ludwigii : Equilibrium and Mechanistic Studies." Open Journal of Applied Sciences 5 (July): 376–92.

[18] Fan, T., Liu, Y.G., Feng, B.Y., Zeng, G.M., Yang, C.P., Zhou, M., Zhou, H.Z., Tan, Z.F. and Wang, X. (2008) Biosorption of Cadmium(II), Zinc(II) and Lead(II) by Penicillium simplicissimum: Isotherms, Kinetics and Thermodynamics. Journal of Hazardous Materials, 160, 655-661

[19] Tasar, S., Kaya, F., ¨Ozer, A., 2014. Biosorption of lead(II) ions from aqueous solutionby peanut shells: equilibrium, thermodynamic and kinetic studies. J. Environ.Chem. Eng. 2, 1018–1026.

[20] Aksu, Z.Z., Isoglu, I.A., 2005. Removal of copper(II) ions from aqueous solution by biosorption onto agricultural waste sugar beet pulp. Process Biochem. 40,3031–3044.

[21] Anayurt, R.A., Sari, A. and Tuzen, M. (2009) Equilibrium, Thermodynamic and Kinetic Studies on Biosorption of Pb(II) and Cd(II) from Aqueous Solution by Macrofungus (Lactarius scrobiculatus) Biomass. Chemical Engineering Journal, 151, 255-261.

[22] Zhu, C., Wang, L., Chen, W., 2009. Removal of Cu(II) from aqueous solution by agricultural by-product: peanut hull. J. Hazard. Mater. 168, 739–746.