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Research Article

Green approach for Ni (II) ion sequestration from aqueous solution using *Phyllanthus emblica seed* coat

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Abstract
Nickel (Ni), a transition element, is widely distributed in the environmental segments through natural sources and anthropogenic activities. Nickel's chronic exposure to human beings may cause allergies, cardiovascular issues, gastrointestinal distress, kidney issues, scarring of the lungs/cancer, inflammation, etc. Nickel compounds can be readily dissolved in water to form hydrated nickel (II) ions in an aqueous medium. The present study investigated the performance of an environmentally friendly adsorbent for sequestering Ni(II) ions from aqueous solution under various conditions. The *Phyllanthus emblica*(Amla) (PE) seed coat was used to remove Ni(II) ions from aqueous solution for the first time. The adsorption capacity of PE has been studied under various conditions, including concentration, pH, dose effect, and equilibrium time, to explore the optimal options for removal. Langmuir, Freundlich and Temkin isotherms were fitted to data. Freundlich fitted better (R^2 = 0.9911), indicating that the adsorption process is more likely heterogeneous and involves multilayer adsorption. Maximum nickel removal was observed at pH 7 and an adsorbent dose of up 0.1g/L.The Langmuir isotherm plot indicated a maximum adsorption capacity (q_{max}) of 15.32 mg/g. Theregeneration studies confirmed that the material can be reused with a small change in its adsorption efficiency after regeneration, making the processes more economical and reducing the amount of waste material.The outcomes of this research maycontribute to sustainable, cost-effective solutions for Ni(II)- contaminated water treatment.

Keywords: Adsorption, Isotherms, Natural adsorbent, Ni(II), Remediation, Water treatment

INTRODUCTION

Water contamination by nickel (Ni) is a persistent environmental challenge arising from various industrial activities, including electroplating, battery manufacturing, and mining. The environmental implications of nickel contamination range from adverse effects on aquatic life to potential human health risks, emphasizing the urgency of developing strategies for its remediation (Adhikari *et al*., 2022; Heikkinen *et al*., 2002; Cempel *et al*., 2006). Its presence in water poses various health hazards like dermatitis, respiratory issues, and carcinogenic effects. Nickel compounds that can be readily dissolved in water form hydrated nickel (II) ions in an aqueous medium. The permissible limits of Nickel (Ni) in drinking water, as prescribed by the World Health Organization (2021), the Environmental Protection Agency (1992), and the Bureau of Indian Standards (2012), are 0.07, 0.1, and 0.02 mg/L, respectively.

Conventional methods used for the removal of contaminants from water, such as chemical precipitation/ion exchange/membrane filtration, often involve high operational costs and also form secondary pollutants. However, the adsorption technique has emerged as a simple, promising, and low-cost sustainable alternative (Xiang *et al*., 2025; Al-Gaashani *et al*., 2024; Awual *et al*., 2024; Rani *et al*., 2020,Parmar *et al*., 2013; Raval *et al*., 2016).Numerous natural/synthetic/modified adsorbents have been tested for the Ni(II) ion remediation from water to achieve good adsorption capacity and reusability of the adsorbents under real environmental

conditions (Al-Gaashani *et al*., 2024; Katal *et al*., 2012; Nnaji *et al*., 2021; Onursal *et al*., 2023). Addressing the challenges of nickel remediation requires a sustainable, multidisciplinary framework that integrates materials science, environmental engineering, and optimisation techniques to remove nickel ions from water. The choice of adsorbent and the optimisation of process conditions are crucial for enhancing the material's performance and enabling efficient removal. This study investigated the performance of an environmentally friendly adsorbent for sequestering Ni(II) ions from nickel-contaminated aqueous solution under various conditionsincluding concentration, pH, dose effect, temperature equilibrium time, etc., to explore the best options for removal using the Indian gooseberry, commonly known as Amla *Phyllanthus emblica* (PE) seed coat using it as natural adsorbent.

MATERIALS AND METHODS

Chemicals used: All Chemicals and reagents used in the present work were of analytical grade and purchased from Central Drug House (CDH).

Preparation of Adsorbent

The natural *P.emblica* fruit was purchased from the local market in Faridabad Sector 16. The preparation of the natural adsorbent involves a meticulous process, from sourcing *P. emblica* fruits to converting its seed coat into a fine powder. The fruit pulp was peeled, and afterwards the seeds were dried for 48-50 hours at room temperature (20-300C) and crushed to obtain the seed coat. The seed coat obtained was further converted to a fine powder and then sieved. This material was used for the removal of nickel.

Preparation of aquatic solution samples and batch studies

Nickel ion solution (100 mg/l) was prepared from Nickel (II) nitrate hexahydrate, $Ní(NO_3)_2 \cdot 6H_2O$. For batch studies, varying-concentration solutions (20-80 mg/L) were prepared from a 100 mg/L stock solution. Different concentrations of samples were used to determine the amount of Ni in the filtrate via Atomic Absorption Spectroscopy (4129DAAS) following the acid digestion method (Mohammed *et al*., 2017), varying the contact time, adsorbent dose, and pH. The adsorption study was performed at room temperature 25^0C. A blank experiment was also conducted without the adsorbent. All the experiments were performed in triplicate to ensure accuracy and reliability. The mechanism of interaction between the adsorbent and adsorbate was evaluated by fitting the batch adsorption results to Langmuir, Frundlich, and Temkin isotherms. These models require the amount of Ni(II) adsorbed and Ni(II) ion residual concentration at equilibrium. These isotherms are most commonly used model in adsorption studies (Saini *et al*.,2018).

Regeneration studies

To assess the adsorbent's reusability, regeneration studies were also conducted. The spent *P. emblica* (PE) biosorbent was subjected to a column regeneration process using 30% H_2O_2 prepared in 0.1 M HNO_2 as the desorbing agent. After desorption, the material was further treated with 0.1 M NaOH to neutralise and restore its active functional groups. The regenerated biosorbent was thoroughly washed with distilled water to remove residual chemicals, then dried in a hot-air oven at 120 °C overnight. The dried adsorbent was collected and stored in airtight containers for subsequent use.

Instrumentation analysis

The functional groups associated with PE based biosorbent and Ni(II) loaded biosorbent were analysed by Fourier Transform Infrared Spectroscopy (FTIR) (Model - Spectrum Two with ATR, Shimadzu). The phase composition of the biosorbent was analysed by X-ray diffraction (Rigaku Miniflex 600) with a scanning rate of 2°/step. Characterisation using an instrument specific to the present study was adopted following the work reported by Sinyeue *et al*. (2022).

RESULTS AND DISCUSSION

Characterization of the adsorbent

Functional groups and other active groups on the *P.emblica* (PE) seed coat were characterized by the FTIR technique. The PE seed coat showed various specific peaks in its IR spectrum. A small peak at 3342.42 cm^{-1} indicated the O–H stretching because of hydroxyl groups of water/cellulose/alcohols or phenols present in PE. Alkane C–H stretching (-CH_3, -CH_2– groups) was observed at 2908.52 cm^{-1}. A small peak at 2361.96 cm^{-1} wasobserved due to CO_2 or C≡C stretching of absorbed gases/background noise. A strong peak at 1726.10 cm^{-1} was observed due to C=O stretching of aldehydes/carboxylic acids/esters in PE. Two peaks at 1368.88 and 1231.01 cm^{-1} indicated C–O–C stretching (ethers/esters) or C–H bending (alkanes). One more sharp peak at 1031.85 cm^{-1} indicated C–O stretching of alcohols/esters. A peak at 667.14 cm^{-1} indicatedC–H bending out of the plane of alkenes/aromatics (Fig.1).

After adsorption of nickel from water, the O-H stretching at 3342.42 cm^{-1} was somewhat shifted, suggesting interactions or hydrogen bonds in PE due to the interaction of nickel. A peak at the same position, 2361.96 cm^{-1}, was observed due to CO_2 or a small amount of contamination. A strong peak at 1738.44 cm^{-1} suggested the interaction of the nickel with the groups. A little change in C–O stretching or C–H bending was ob-

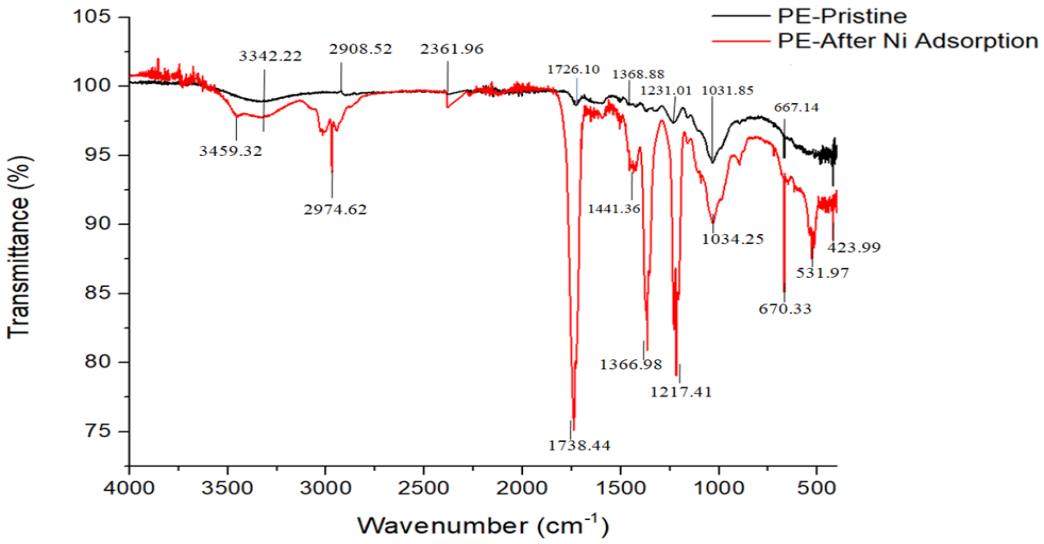

Fig. 1. *Fourier transform infrared spectroscopy (FTIR) spectra of PE before and after adsorption of nickel in Phyllanthus emblica (PE) seed coat*

served due to interaction at 1366.98 / 1217.41 cm^{-1}. C–O stretching at 1031.29 cm^{-1} was slightly shifted due to potential interaction with the development of a new bond. The large peak at 3459.32 cm^{-1} of the hydroxyl group (O–H) indicated adsorption of nickel. Strong carbonyl group peak with modest alterations in C–O and C –H bending/stretching peaks indicated surface alteration due to adsorption of nickel. Similar functional groups on surface of *Lysinibacillus sp*. BA2 was identified for removal of Ni (II) ions (Prithviraj *et al*., 2014). In another study, similar peak shifts, such as from 3200-3550 cm^{-1} and from 1600-1700 cm^{-1}, were observed for Ni(II) removal from fungal biomass (Rahman *et al*., 2014).

X-ray diffraction (XRD) studies

XRD is another important technique to identify the structural change in the adsorbent after the adsorption of nickel. In the spectrum, the upper spectrum represents XRD of *Phyllanthus emblica* (PE) seed coat before adsorption, and the lower spectrum represents *Phyllanthus emblica* (PE) seed coat after adsorption of nickel. The PE crystallinity was high before nickel adsorption, with a sharp, more intense peak near 2θ ≈ 22.6°.The crystallinity of PE significantly decreased after adsorption of the nickel metal ion, leading to structural disorder. Also, slightly broader peaks in the PE after adsorption indicated the interaction of the nickel with the surface molecules, which resulted in a decrease in crystallite size. However, no major change in the peak position indicated that no significant phase transformation in the PE structure was observed after nickel adsorption. High baseline in the PE after adsorption of nickel indicated a less ordered structure (amorphous materials) after nickel adsorption (Fig. 2).

Adsorption studies

Adsorption studies were carried out in batch mode to determine the optimal values of material dose, time, and pH of the nickel solution for nickel ion adsorption. To study the effect of PE dose on the adsorption of bivalent nickel ions from water, a Ni(II) solution (60 mg/L) and adsorbent material at varying concentrations (0 - 0.2 g/L) were used, and the mixture was agitated in a rotary shaker for a fixed period of time, followed by filtration.AAS was used to determine the concentration of residual nickel ions in the solution. The concentration of Ni(II) ions to determine the amount of Ni was determined using a 4129 DAAS Atomic Absorption Spectrophotometer operating at a wavelength of 232.0 nm under air–acetylene flame conditions. Calibration was performed using Ni(II) standard batch solutions prepared from a 1000 mg/L stock solution within the required concentration range. The calibration curve showed excellent linearity, with a correlation coefficient (R^2) of 0.9992. Detection limit of 0.002 mg/L was obtained. Each measurement was carried out in triplicate, and mean values were used for quantification.

From the results, it was determined that adsorption increased rapidly up to 0.1 g/L, after which a negligible change was observed. The initial increase in the number of ions adsorbed is attributable to enhanced accessibility of active adsorption sites.

The role of pH on nickel ion adsorption was also studied by taking a nickel ion(60 mg/L) and sorbent PE (0.06 g/L) in the pH range of 1.0 - 9.0, which is maintained by using 1-2 drops of acid (H_2SO_4) or base (NaOH) at other constant factors including initial Ni(II) concentration 60 mg/l, 0.1 g/l adsorbent dose, 180 min contact time, 25 ^{0}C temperature. After agitating the flask on a rotary shaker at RT (room temperature), the solution mixture was filtered. The filtrate obtained was

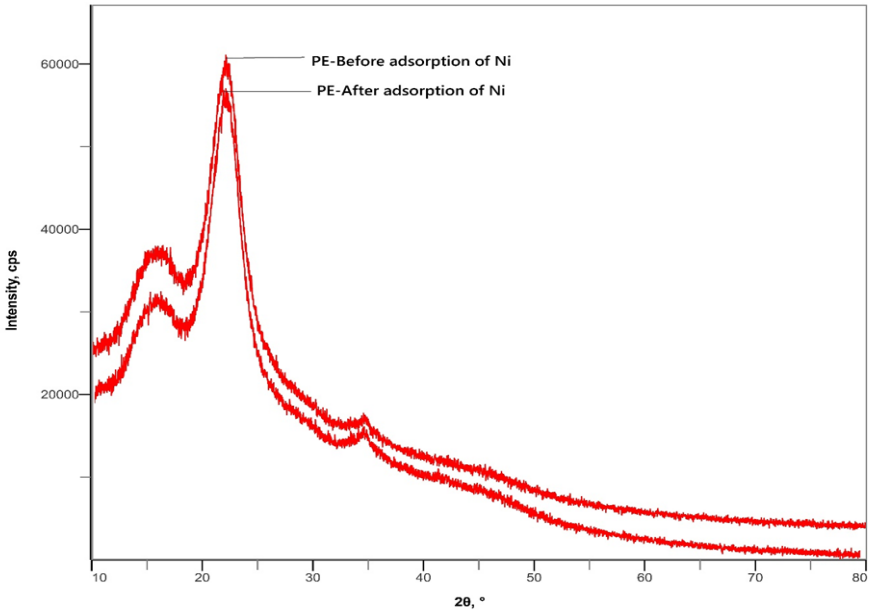

Fig. 2 .*X-ray diffraction (XRD) spectra of PE (before and after adsorption of nickel)*

analysed by AAS to determine the uptake of nickel ions in the different samples under study. Uptake of ions by PE increases with increase in pH till 7.0. Maximum uptake of metal ion was obtained at pH 7.0.It is confirmed in many reported studies that the adsorption of positively charged ions is favoured at pH values above the isoelectric point (Srivastava and Hasan, 2011; Gupta *et al*., 2019). A negative surface charge at pH values above the isoelectric point supports the adsorption of cations.

To determine the optimal contact time for nickel ion uptake, the adsorption experiment was conducted at 20, 60, 120, and 240 minutes, while other conditions remained constant. Results demonstrated that nickel (II) ion adsorption increased with increasing contact time up to 180 min. This may be attributed to the reason that numerous vacant sites are available initially for adsorption of nickel ions, but with time (after 180 minutes), no appreciable change was observed because of the availability of fewer vacant sites for uptake of nickel ions.

Adsorption isotherm

The adsorption isotherm obtained from batch adsorption data reveals the adsorption mechanism of Nickel ions from aqueous solution on the sorbent PE and the material's maximum adsorption capacity. To ascertain the adsorption capacity of PE, three main isotherms (Langmuir, Freundlich and Temkin) were applied to the data obtained.

Langmuir isotherm

The Langmuir model assumes that adsorption of ions from an aqueous system occurs as a reversible monolayer process on the sorbent surface, and that each adsorbate molecule can both adsorb and desorb. The adsorption may proceed via chemisorption/ physisorption mechanisms. The linear Langmuir isotherm is expressed as follows:

$$1/q_e = 1/(q_{max} * K_L) * 1/C_e + 1/q_{max} \quad (1)$$

Equation (1) was used to calculate the adsorption capacity of PE, where Ce is the equilibrium concentration of bivalent nickel ions in solution, and qe is the equilibrium concentration of bivalent nickel ions adsorbed on PE.K_L represents the Langmuir constant, while qmax denotes the maximum adsorption capacity of sorbent PE, expressed in mg/g. The Langmuir isotherm also helps calculate the separation factor, RL, which indicates whether adsorption is favourable or unfavourable.

$$R_L = 1/(1+(K_L q_{max}) \quad (2)$$

The separation factor may have any value (zero/ positive/or negative). Zero separation indicated an irreversible isotherm representing very strong adsorption. A separation factor (R_L) equal to 1 indicates a linear isotherm, while a value between 0 and 1 suggests favourable adsorption conditions. Conversely, an R_L value greater than 1 indicates that adsorption is not favourable. For the PE separation experiments, the separation factor was 0.57, indicating favourable conditions for nickel ion adsorption (Table 1). Qmax was found to be 15.32 mg/g, and the K_L was determined as 0.05 L/g, as obtained from the plot shown in Fig. 3.

Freundlich isotherm

Freundlich model also analysed multi-layered adsorption of bivalent nickel ion from solution on PE. Information onmulti-layered adsorption of nickel can be derived by plotting a graph (ln qe versus ln Ce), where the slope corresponds to 1/n and the intercept to ln K_F. The standard linearized form of the Freundlich isotherm is

Table 1. Results of Langmuir. Freundlich and Temkin isotherm models

Langmuir			Freundlich		Temkin	
Adsorption capacity q_{max} (mg/g)	R_L (l/mg)	R_2	n	R_2	B	R_2
15.32	0.57	0.9875	1.41	0.9911	5.231	0.9609

given as follows:

$$\ln q_e = \ln K_f + 1/n \ln C_e \quad (3)$$

Here, K_f is Freundlich constant; where Ce is the equilibrium concentration of bivalent nickel ions in solution, and qe is the equilibrium concentration of bivalent nickel ions adsorbed on PE. The slope (1/n) reflects the adsorption potential, while n indicates the adsorption intensity and the degree of deviation from linearity (Fig. 4). An n value between 1 and 10 typically signifies favourable adsorption. In the present study, the value of n was found to be 1.41, confirming favourable adsorption conditions. A summary of the other results is provided in Table 1.

Temkin isotherm

The Temkin isotherm accounts for interactions between adsorbed molecules and is not appropriate for extremely high or low concentration solutions; it is best suited to moderate concentration values. It can be expressed as follows:

$$q_e = B \ln A + B \ln C_e \quad (4)$$

Where Ce is the equilibrium concentration of bivalent nickel ions in solution, and qe is the equilibrium concentration of bivalent nickel ions adsorbed on PE. A is Temkin constant (equilibrium binding constant), and heat sorption constant B is in J/mol (Fig. 5). The results obtained are given in Table 1.

Based on the comparative analysis of regression correlation coefficients (R^2), the adsorption of nickel ions on the PE surface is best described by the Freundlich isotherm model, as its R^2 value is closer to unity compared to those of the Langmuir and Temkin models.It can be concluded that the adsorption process is more likely to be heterogeneous and involves multilayer adsorption.

The main components of the seed coat of PE are depicted in Fig. 6, which further helps to understand the PE-Ni interactions during the removal process. However, key components of seed coat oil included various acidic compounds, such as aspartic acid, glutamic acid, and tetra decanoic acid. It also containscotadeca-9,12,15-trienoicacid and other fatty acid. Amino acids are important components of the seed coat of PE (Kulkarni *et al*., 2018; Ahmad *et al*., 2021).

Nickel (Ni(II)) adsorption on PE may involve several physicochemical mechanisms. Functional groups, including carboxyl (-COOH), hydroxyl (-OH), and amino ($-NH_2$) groups, can form coordinate bonds with nickel ions, facilitating strong metal binding through ion-exchange/complexation reactions. Also, at lower pH, less adsorption was observed, as the PE surface may be less negatively charged; as pH increases, deprotonation of surface groups enhances negative charge, increasing electrostatic attraction to positively charged Ni(II) ions. Both methods jointly affect the efficiency and capacity of organic materials to remove nickel from aqueous environments.

Regeneration studies

To make the adsorption process cost-effective and environmentally safe, recycling and reuse of the adsorbent after desorption, along with the cost and availability of the adsorbent material, are crucial aspects in adsorption studies (Renu *et al*., 2024). The process under study is very economical as part of fruit used in the study is often discarded. Regeneration of the used adsorbent material is also very important in determining the adsorbent's practical useability. After the batch studies, PE was regenerated by designing a column (Lata *et al*. 2015)and stored for further use. The Langmuir q_{max} after regeneration of the PE was observed to

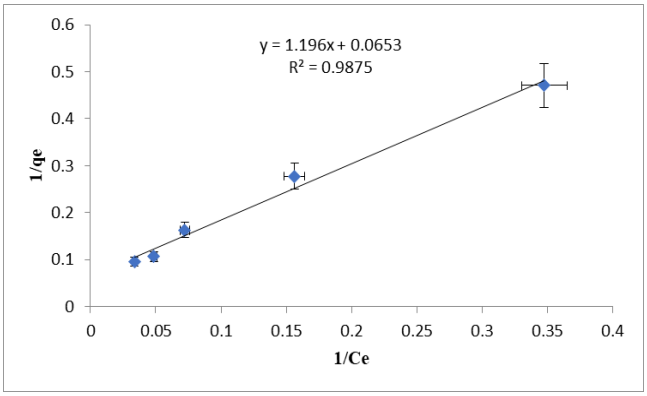

Fig. 3. *Langmuir isotherm of adsorption of Ni (II)*

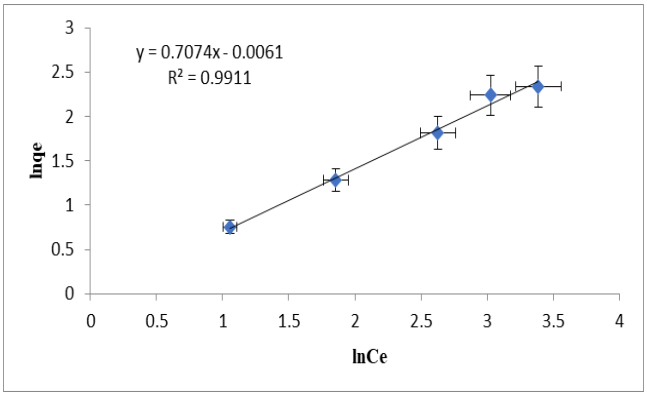

Fig. 4. *Freundlich isotherm of adsorption of Ni(II)*

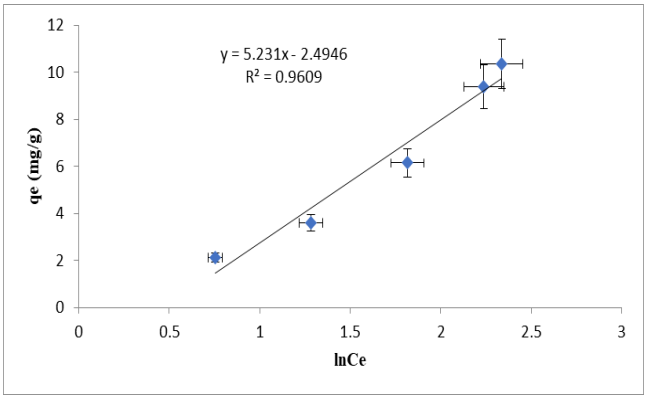

Fig. 5. *Temkin isotherm of adsorption of Ni (II)*

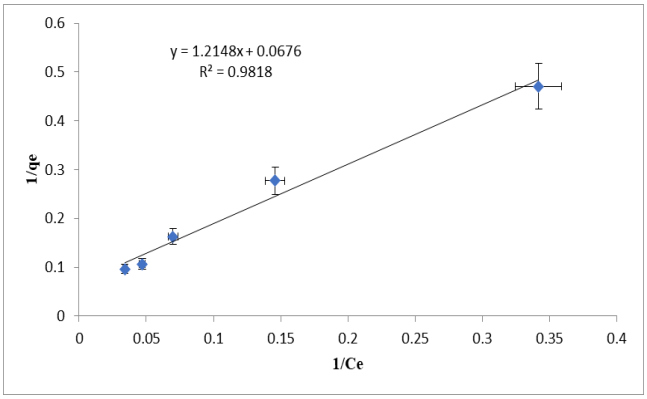

Fig. 7. *Langmuir isotherm of adsorption of Ni(II) after regeneration*

be 14.79 mg/g (Fig. 7).More than 90% efficiency was achieved upto 3 cycles studied for the desorbing process. It can be concluded that PE isa promising economic material for nickel remediation under various conditions. Optimum removal of nickel was achieved at 60 mg/L of nickel solution with an adsorbent dose of 0.1 g/L at pH 7.0 within 180 min of contact time.

Comparative study with other adsorbents

Nickel removal from water has been widely explored using plant-based, agricultural waste like Palm kernel chaf, Gooseberry Seeds etc. and modified adsorbents (Aravind *et al*., 2017; Awual *et al*., 2024; Nnaji *et al*., 2021) . Table 2 shows the performance of different materials used for the removal of nickel ions from water. Materials such as grapefruit peel, tea factory waste, zeolite-doped nanocomposites, and meranti sawdust exhibit strong metal-binding capacity due to surface functional groups, including hydroxyl, carboxyl, and amine. These natural adsorbents are cost-effective, eco-friendly, and often match or even surpass synthetic materials in efficiency, especially at low metal concentrations. However, their performance depends on factors such as pH, contact time, initial nickel concentration, and regeneration capacity as shown in table 2. Therefore, selecting the right adsorbent depends on the specific conditions, local material availability, and the

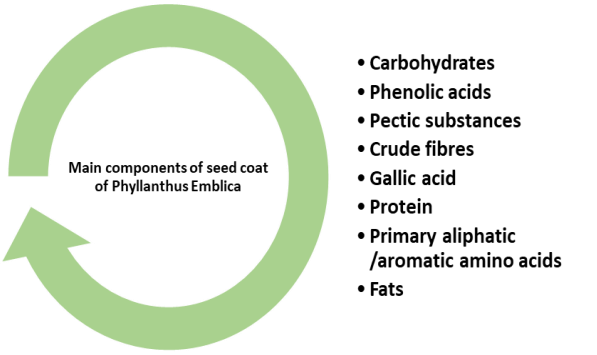

Fig. 6. *Main components of phyllanthus emblica (PE) seed coat*

operational needs of the treatment system.

The material used in the present study, the *P. emblica* seed coat-based adsorbent, was found to be significant for the removal of Ni(II) ions from synthetic wastewater at pH 7. The maximum adsorption capacity was found to be 15.32 mg/g at an optimum pH of 7, which is better than that reported for the materials at pH 7. Table 2 provides a comparative analysis of the optimum conditions and the maximum adsorption capacity for Nickel Removal using natural and synthetic adsorbents. Although various researchers have reported higher adsorption capacities for Ni(II) removal, most have achieved these results under either acidic or highly alkaline conditions (Awual *et al*., 2024; Nnaji *et al*., 2021; Torab-Mostaedi *et al*., 2013). However, in the present study, pH 7 was found to be optimal for maximum adsorption. Thus, no further acidic or alkaline substances were added to the water during the metal removal process.

Conclusion

Ni(II) adsorption from aqueous solution using *P. emblica* seed coat: Langmuir, Freundlich, and Temkin isotherms were fitted to the data. Freundlich fit better (R^2 = 0.9911), indicating that the adsorption process was more likely to be heterogeneous and involved multilayer adsorption. The results of adsorption batch studies showed that the adsorption capacity is influenced by pH. Maximum nickel removal was observed at pH 7, while lower pH levels inhibited removal, because of the competitive mobility of H^+ and Ni^{2+} ions for adsorption sites. Nickel uptake increased with the adsorbent dose up to 0.1g/L, beyond which it reached a steady state. The Langmuir isotherm plot indicated a maximum adsorption capacity (q_{max}) of 15.32 mg/g. The generation studies confirmed that the *P. emblica* (PE) seed coat, as an adsorbent material, can be regenerated and reused with a small change in its adsorption efficiency after regeneration, making the process more economical and reducing the amount of waste material. Ni(II)

Table 2. Performance of adsorbents for the removal of Ni(II) ions from water under different conditions

Details of adsorbent	The optimum conditions of sorption	Maximum adsorption capacity/ maximum % age assorption	Reference
Malatya clay	Sorbent amount- 5g/L, contact time -360 min, and pH- 6.27	10.267 mg/g	Onursal *et al*., 2023
Palm kernel chaf (without carbonization)	Sorbent amount- 1g/L, contact time -120 min, and pH- 9	65.9 mg/g	Nnaji *et al*., 2021
Gooseberry seeds	Sorbent amount- 3 g/L, contact time 90 min, and pH- 3.	59%	Aravind *et al*., 2017
Grapefruit peel	Sorbent amount- 4 g/L, contact time -120 min, and pH- 4.	46.13 mg/g	Torab-Mostaedi *et al*., 2013
Charcoal ash	Sorbent amount- 30 g/L , contact time -60 min, and pH- 4.	16.3 mg/g	Katal *et al*., 2012
Meranti sawdust	Sorbent amount- 5g/L, contact time -180 min, and pH- 6	35.971 mg/g	Rafatullah *et al*., 2009
Tea factory waste	pH- 4	15.26 mg/g	Malkoc *et al*., 2005
Zeolite-doped magnesium-iron- and zinc-oxide nanocomposites	Sorbent amount- 3 g/L, contact time -240 min, and pH- 7.	17.13 mg/g	Al-Gaashani *et al*., 2024
mesoporous silica and composite adsorbent (MCA)	Sorbent amount- 0.01g/L, contact time -180 min, and pH- 5.5	167.55 mg/g	Awual *et al*.,2024
Al_2O_3@g-C_3N_4 (AlCN)	Sorbent amount---, contact time -1440 min, and pH- 7	410.2 mg/g	Aldoihi *et al*.,2024
Palm kernel chaf (Carbonized)	Sorbent amount- 1g/L, contact time -120 min, and pH- 9	120.6 mg/g	Nnaji *et al*., 2021
Magnetic chitosan beads	Sorbent amount- 0.05g/L, contact time -60 min, and pH- not mentioned	0.064 mg/g	Rani *et al*., 2020
Magnetic chitosan beads' derivative	Sorbent amount- 0.05g/L, contact time -60 min, and pH- not mentioned	0.076 mg/g	Rani *et al*., 2020
Modified zeolite	Sorbent amount- 12g/L, contact time -240 min, and pH- 7	0.433 mol/kg	Pahlavanzadeh *et al*., 2019
Zeolite	Sorbent amount- 10g/L, contact time -240 min, and pH- 7.5.	65.66 mg/g	Wassel *et al*., 2016
activated carbon	Sorbent amount- 10g/L , contact time -120 min, and pH- 7.5	44.1 mg/g	Ewecharoen *et al*., 2009
Irradiation-grafted activated carbon	Sorbent amount- 10 g/L , contact time -120 min, and pH- 7.5	55.7 mg/g	Ewecharoen *et al*., 2009
Chemically treated *Calotropis biomass*	Sorbent amount- 1-25g/L, contact time -30 min, and pH- 3	15.75 mg/g	Pandey *et al*., 2007
Phyllanthus emblica Seed Coat	Sorbent amount-0.1g/L, contact time 180 min, and pH- 7.	15.32 mg/g	Present study

adsorption from aqueous solution using *P. emblica* seed can be a sustainable alternative for the remediation of Ni(II)- contaminated water. Further research can focus on optimizing adsorption conditions and evaluating the method's scalability for large-scale applications. The performance of *P. emblica* seed coat in continuous -flow systems with real water samples can also be studied to check the efficiency of the sorbent material for the removal of Nickel and other target contaminants.

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Conflict of interest

The authors declare that they have no conflict of interest.

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