Adsorbent potential of the leaf powder of *Artocarpus heterophyllus* Lam. (jackfruit) in efficiently removing hexavalent chromium from landfill leachate

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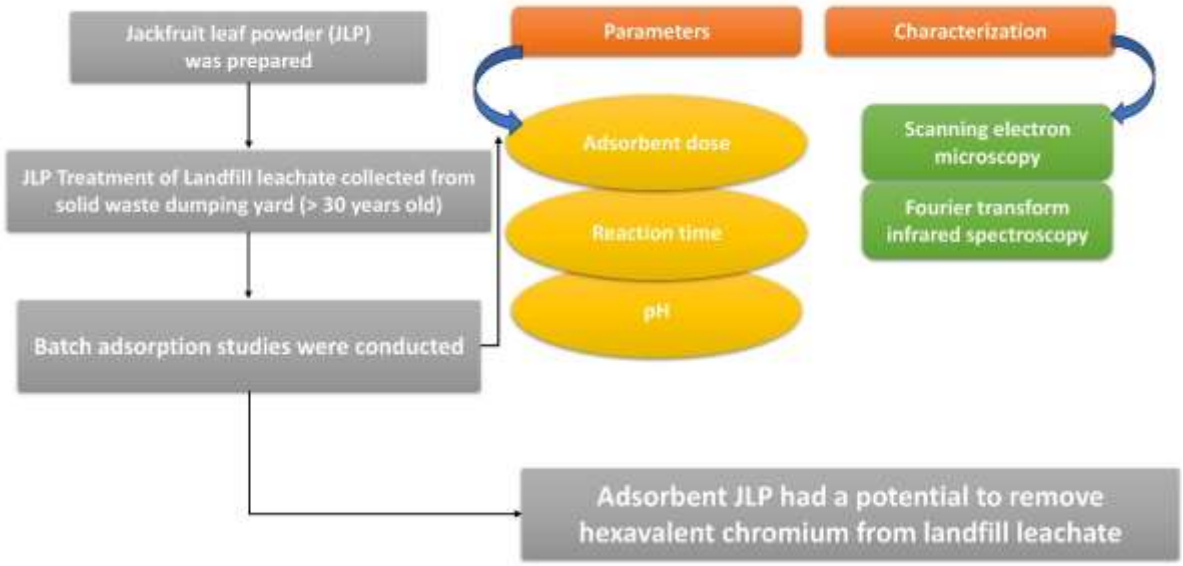
GRAPHICAL ABSTRACT



Abstract

Chromium (VI), a ubiquitous toxin, has been associated with several human cancer types as well as immunologic, cardiovascular, developmental, neurological, and endocrine disorders. The present study investigated the selective adsorption capacity and chromium (VI) removal ability of jackfruit leaf powder (JLP, *Artocarpus heterophyllus* Lam.) in landfill leachate collected from eastern region of southern India. The efficiency of prepared JLP in removing chromium (VI) from landfill leachate was examined using a number of variables such as adsorbent dose, pH, and reaction time by employing the batch adsorption process. The maximum chromium removal efficiency was observed by increasing the adsorbent dose, pH, and reaction time, while the optimal dose of JLP, pH, and adsorption reaction time were found to be 0.5 g/L, pH 8, and 120 min, respectively. Batch adsorption process under optimal conditions showed adsorption capacity value of 0.19 mg/g and the chromium (VI) removal efficiency of 95%. The data were examined using kinetic and equilibrium models. The experimental data and the Freundlich isotherm and pseudo-second order kinetics models were well-matched. The SEM and FT-IR of fresh and recovered JLP revealed similar surface morphology and functional characteristics, representing the active site present in the adsorbent (JLP) showing no significant change. We performed experiments on chromium (VI) recovery

from the adsorbent that resulted in the higher recovery % of chromium (VI) with 0.5 M HCl (90%). The results suggest that JLP may be employed as a cost-effective bio-adsorbent for the removal of chromium (VI) from contaminated soil and water resources.

Key words: Jackfruit leaf powder; Bio-adsorbent, Batch adsorption, Chromium (VI) removal, Isotherm, Kinetics models

1. Introduction

Globally, the landfilling process is used to dispose up to 95% of the municipal solid waste (MSW) (Kurniawan *et al.*, 2006). Landfill method is considered one of the most cost-effective methods for disposing MSW and industrial solid waste (Detho *et al.*, 2021). The dispersion of pollutants from landfill leachate could cause deterioration of soil, surface water, and groundwater (Sangeetha *et al.*, 2023; Deng and Englehardt, 2006). Leachate contains a large amount of inorganic and organic compounds such as heavy metals, sulphate, chlorides, and refractory compounds (Sangeetha *et al.*, 2023). The leachate concentration varies depending on numerous factors such as precipitation, age of landfill, and type of waste and composition (Mahtab *et al.*, 2021). The landfill leachate age is classified into three major categories: young (less than 5 year-old), intermediate (between 5 and 10 year-old), and old or mature (more than 10 year-old) (Deng *et al.*, 2021; Li *et al.*, 2022; Lu *et al.*, 2023; Sangeetha *et al.*, 2023). The precipitated liquid comes in contact with dumped wastes; it leaches the hazardous chemicals, heavy metals, toxic constituents, and some emerging contaminants like pharmaceuticals and personal care products, endocrine disrupting compounds, and persistent organic pollutants, among others (Sanguanpak *et al.*, 2019). This may cause various health complications, including liver pathology, kidney abnormalities, skin irritation, genetic damage and birth defects. In addition, the leachate contains toxic harmful chemicals, which may cause cancer or other serious harm to human health, aquatic organisms and ecosystems (Chen *et al.*, 2021; Sanguanpak *et al.*, 2019). Hexavalent chromium (Chromium (VI)) has been suggested to be the most toxic valence state of chromium, and is commonly present in industrial effluents and wastes (Yang *et al.*, 2021).

Industrial effluents and waste water are the main environmental sources of chromium (VI) (Sharma *et al*., 2022). Due to its long persistence in the environment and extremely lethal nature in living beings, chromium (VI) pollution has emerged as one of the most serious environmental challenges in the world (Sharma *et al.*, 2022). Due to its widespread use in

industries, chromium (VI) is one of the most prevalent environmental pollutants and is also considered very hazardous (Sharma *et al.,* 2022). Because chromium (VI) is typically not biodegradable in nature, it pollutes the soil and water, persists in the environment for a long period, and poses serious health hazards to both human and animals (Sharma *et al.,* 2022). Moreover, chromium (VI) has been suggested to be mutagenic, genotoxic, and carcinogenic to living beings (Sharma *et al.,* 2022). By inhalation and skin contact, chromium (VI), an ubiquitous toxin, has been associated to a wide range of human cancer types as well as immunologic problems, cardiovascular, developmental, neurological, and endocrine ailments (Iyer *et al.,* 2023). Therefore, treatment of landfill leachate constituents like chromium (VI) before discharge has been made a legal requirement that is of utmost importance to reduce the risk of chromium (VI) contamination of water resources (Abbas *et al.,* 2009; Cherdchoo *et al.,* 2019). Consequently, there is a great demand for efficient technologies to remove chromium (VI) from landfill leachate. Many conventional technologies have been employed for the removal of chromium (VI) from waste water such as ion exchange resins, coagulation and precipitation, solvent extraction and membrane-based separation (Cherdchoo *et al.,* 2019; Singh *et al.,* 2022). These technologies, however, have some key limitations such as expensive, effluent disposal, producing sludge (secondary pollutant), and safety concern (Gupta *et al.,* 2023). Moreover, the physico-chemical methods now employed for removing chromium (VI) are not eco-friendly because of their processes involving a large number of chemicals (Sharma *et al.,* 2022). On the other hand, in order to reduce these limitations, natural bio-adsorption is employed as one of the most attractive and alternatives techniques because of its cost effectiveness, easy operation, and eco-friendly potentials.

Nowadays, a growing body of evidence suggests the use of plant parts as low-cost bio-adsorbents for the removal of heavy metals and dyes from the ground water and synthetic wastewater (Elangovan *et al.,* 2015; Gupta *et al.,* 2023; Das and Mishra, 2019). Previous studies employed neem leaves, coconut shell, sawdust, rice straw, rice bran, rice husk, hyacinth root, fly ash, rubber leaf powder, onion peel, bamboo leaf, mango leaf, and among others, as green adsorbents for the removal of chromium (VI) ion from wastewater (Mitra and Das, 2019).

A few studies have reported that jackfruit leaf, seed, and peel are considered to be an effective adsorbent for the removal of various heavy metals such as nickel (II), chromium (VI) and lead (II) from aqueous solution and synthetic wastewater (Boruah *et al.,* 2015; Lubanga *et al.,* 2017; Saranya *et al.,* 2018; Gupta *et al.,* 2023). This plant leaves have lignocellulose and are available in larger quantity in the tropical region of the world (Gupta *et al.,* 2023). Jack

fruit leaves contains various phytochemicals, including phenolic acids, flavonoids, tannins, terpenoids, glycosides, saponins, alkaloids, and among others (Aguilar-Veloz *et al*., 2022).

To the best of our knowledge, the efficiency of jackfruit leaf powder (JLP) on the removal of chromium (VI) in landfill leachate has not been well-known. Therefore, the present study has been designed to investigate the efficiency of JLP as an adsorbent to remove chromium (VI) from landfill leachate. The key objectives of the present study include (i) to assess the operating parameters such as adsorbent dose, contact time, and pH on the removal of chromium (VI) from the landfill leachate, (ii) to analyse the data using kinetic and equilibrium models in the removal of chromium (VI), (iii) to characterize the bio-adsorbent using scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) before and after the treatment, and (iv) to perform desorption study demonstrating the chromium (VI) recovery from the adsorbent (JLP).

2. Materials and methods

2.1. Materials

All the chemicals employed in the present study were procured from Techno scientific chemical company Pvt. Ltd, Thanjavur, India and they are of analytical grade, hence used without further purification. The chemicals procured are phosphoric acid, acetone, nitric acid, sulphuric acid, hydrochloric acid, 1.5-diphenylcarbazide, sodium hydroxide, among others.

2.2. Collection of samples

The jackfruit leaf was collected from residential area located at Nanjikottai village of Thanjavur, India. Ten litre (10 L) of old landfill leachate was collected from Thanjavur municipal solid waste dumping yard (> 30 years old). Prior to characterization, it was filtered to remove the suspended impurities and was stored at 4 $^{\circ}$C to avoid any biological oxidation.

2.3. Preparation of the adsorbent

The fresh jackfruit leaves were collected and then washed thoroughly in running tap water to remove dust particles and soil, and then rewashed with double distilled water to remove any remaining minor contaminants. The washed material was dried in a hot air oven (80 °C) for 48 hours. Subsquently, the dried leaves were crushed and sieved through a sieve analyser (40-100 mesh). The processed JLP is kept in an airtight container for experimental evaluations (Figure 1).

Figure 1. Jackfruit leaf powder as an adsorbent

2.4. Experimental procedure

Batch adsorption studies were conducted at room temperature (25 ± 3 °C) to investigate the adsorption potential of JLP for the removal of chromium (VI) from landfill leachate. In batch adsorption study, 100 mL of landfill leachate was taken in a conical flask of 250 mL capacity. Then, the required pH was adjusted using 1N H_2SO_4 and 1N NaOH. The effect of experimental variables such as adsorbent dose (0.1-2 g/L), pH (2–9) and contact time (15-150 min) were evaluated. The mixer was kept in an orbital shaker at 150 rpm for about 150 min at room temperature. The samples were drawn at every 15 min of time intervals and centrifuged for 5 min at 6000 rpm, while 10 mL of supernatant liquid was collected and filtered using a syringe filter. The concentration of chromium (VI) was estimated in the filtered sample using UV-visible spectrophotometer at 540 nm. In this context, the standard calibration curve was plotted using various concentrations of chromium (VI) (0, 20, 40, 60, 80, 100, 120 µg/mL) (R^2 = 0.8614). The physico-chemical parameters of leachate were studied as per the standard method of the American Public Health Association (APHA, 2012). All experiments have been performed at triplicates. The percentage of chromium (VI) removal and adsorption capacity were calculated using the following equation (1) and (2), respectively.

$$\text{Chromium (VI) removal percentage R (\%)} = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

$$\text{Adsorption capacity qe (mg/g)} = \frac{C_0 - C_e}{m} \times V \quad (2)$$

Where, C_0 (mg/L) and C_e (mg/L) are the initial and final concentration of chromium (VI) respectively, m is the mass of JLP adsorbent (g), and V is the volume of solution in (L).

2.5. Kinetic models for chromium (VI) adsorption

The kinetic models for the adsorption study have been thoroughly explored in order to assess the effectiveness of the adsorption process. The adsorption kinetics of chromium (VI) onto synthesised JLP were examined using two kinetic models, the pseudo-first-order and pseudo-second-order models, which predict the proper adsorption mechanism. In pseudo-first-order kinetics equation, adsorption in solid-liquid systems were characterised by determining the adsorption capacity of solids. A chemisorption process from liquid solutions has been expressed by the pseudo-second-order kinetics equation (Wang *et al.,* 2015). The related equations and parameters are as follows:

2.5.1. Pseudo -first-order

The linear Lagergren pseudo-first-order mathematical equation is expressed as shown in Eqn. 3 (Ranasinghe *et al.,* 2018; Tahiruddin *et al.,* 2023).

$$\log(q_e - q_t) = \log(q_e) - \frac{k_1}{2.303} t \qquad (3)$$

Where q_e and q_t (mg/g) are the amounts adsorbed at equilibrium and time t (min), respectively, and k_1 is the pseudo-first-order rate constant (min).

2.5.2. Pseudo-second-order

The linear form of pseudo-second-order model can be expressed as shown in Eqn. 4 (Ranasinghe *et al.,* 2018; Revellame *et al.,* 2020).

$$\frac{t}{q_e} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \qquad (4)$$

Where q_e and q_t (mg/g) are the amount adsorbed at equilibrium and time t (min), respectively; k_2 is the pseudo-second-order adsorption rate constant (g/mg min).

2.6. Adsorption isotherm model

2.6.1. Langmuir isotherm

The surface is assumed to be uniform by the Langmuir isotherm. There are a limited number of adsorption sites, and a site cannot be taken up by a new molecule until the one that was previously adsorbed vacates it. The maximum adsorption rate and maximum sorption rate are equivalent in this model's description of the equilibrium monolayer adsorption process. On the surface of a solid, there are no forces between adsorbed molecules. The linear Langmuir isotherm can be expressed as shown in Eqn. 5 (Ali *et al.,* 2020; Ali *et al.,* 2021).

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

where K_L is the Langmuir constant indicating the adsorbent-adsorbate (L/mg), q_e and q_m are the equilibrium and maximum ion capacity (mg/g), and Ce is the equilibrium concentration (mg/L).

2.6.2. Freundlich isotherm

The Freundlich isotherm can be used to represent both chemisorption (monolayer) and physisorption (multilayer). This model is based on the equilibrium of heterogeneous adsorption on the surface of an adsorbent. The linear form Freundlich isotherm can be expressed as shown in Eqn. 6 (Ali *et al.*, 2020; Ali *et al.*, 2021).

$$log\ q_e = logK_F + \frac{1}{n} logC_e \quad (6)$$

where K_F and n are the Freundlich isotherm constants related to adsorption capacity and adsorption intensity, respectively, and Ce is the equilibrium concentration (mg/L).

$$R_L = \frac{1}{1+K_L C_0} \quad (7)$$

Where R_L is a dimensionless equilibrium parameter; and Co is the initial concentration of chromium (VI) (mg/L).

2.7. Analytical methods

The pH of the solution was measured using pH meter with glass electrode (Labman-LMPH-10). The chromium (VI) concentration was measured using UV-visible spectrophotometer at 540 nm (Shimadzu-UV 19001). The functional groups of the fresh and recovered adsorbent were characterised using FTIR (FTIR-Thermo Nicolet-Nexus 670, USA) at wave numbers ranging from 4000 cm^{-1} to 500 cm^{-1}. To examine the surface morphology, JLP was analysed using SEM (Philips XL30) at an electron acceleration voltage of 15 kV. Freshly prepared JLP and recovered JLP were mounted on a stainless-steel stab with double stick tape and coated with a thin layer of gold under high vacuum.

3. Results and discussion

3.1. Leachate characteristics

The physio-chemical analyses of leachate were carried out as per the standard method (APHA, 2012). The pH (8.3), COD (3489 mg/L), $BOD_{5,20}$ (78 mg/L), total suspended solids (976 mg/L), total dissolved solids (8569 mg/L), total hardness (1458 mg/L as $CaCO_3$), and chromium (VI) concentration (5 mg/L) were determined.

3.2. Optimization of process parameter

3.2.1. Effect of reaction time

The influence of reaction time on the efficiency of chromium (VI) removal is shown in figure 2, which reveals that chromium (VI) removal efficiency increases from 30.67% to 94.5% when increasing the time ranging from 15 min to 120 min, respectively. However, increasing

the reaction time over 120 min resulted in only a minimal increase in chromium (VI) removal, suggesting that the process equilibrium is achieved. The major reason for the occurrence of above phenomenon may be due to decreases in availability of active sites as well as the driving force resulting in lesser transfer of metal ions onto the surface of the adsorbent (Ojha and Bulasara, 2014; Khadem *et al.*, 2022). The optimum contact time of the prepared adsorbent for the removal of chromium (VI) in landfill leachate was therefore fixed at 120 min for further studies.

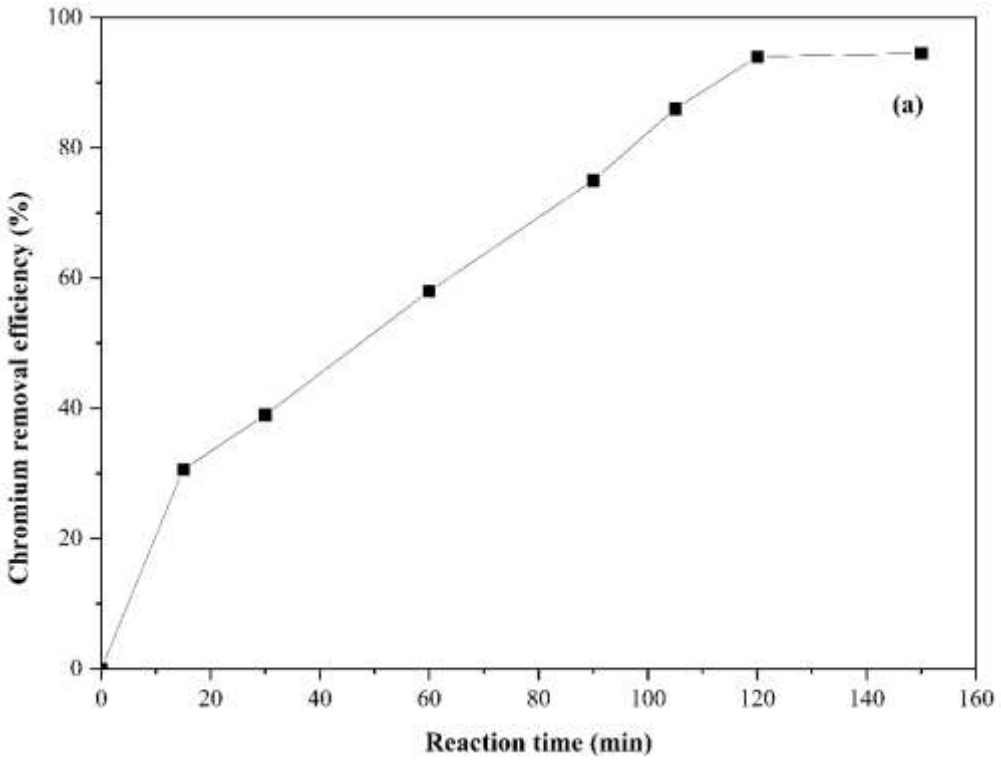


Figure 2. Effect of Reaction time

3.2.2. Effect of adsorbent dose

The impact of JLP adsorbent dose on the adsorption of chromium (VI) is shown in figure 3, which reveals increase in the chromium (VI) removal efficiency from 54.2% to 95.6% with increasing JLP loading dose from 0.1 to 0.5 g/L. However, further increasing doses from 1 to 2 g/L did not favor for high removal of chromium (VI) from 95.78% to 96.17 %, respectively. The removal efficiency increases with increasing JLP dose due to the high number of adsorption active sites with increase in surface area and more availability of binding sites. However, subsequent saturation might have obtained after subjecting a high adsorbent dose that could have produced a steady state adsorption (Zhou *et al.,* 2019; Dutta *et al.,* 2022; Lyu *et al.,* 2017). Similar results were reported while removing various pollutants such as chromium (VI), Congo red, and methyl orange (Dutta *et al.,* 2022; Extross *et al.,* 2023; Singh *et al.*,2022).

On other hand, when increasing the JLP dose from 1 g/L to 2 g/L, the adsorption capacity (qe) reduced from 0.096 to 0.048, perhaps, due to the lesser utilization active site (Dutta *et.al* 2022). Thus, the optimum adsorbent dose to remove the chromium (VI) was found to be 0.5 g/L.

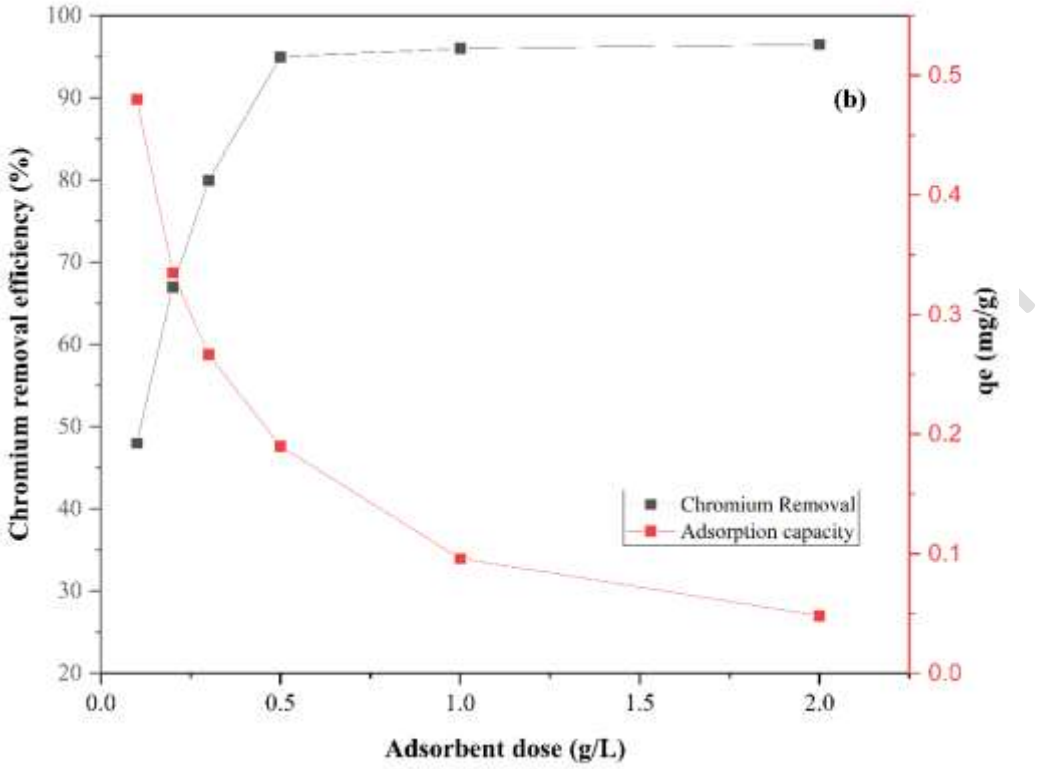


Figure 3. Effect of adsorbent dose

3.2.3. Effect of pH

The pH of the solution is an important parameter during the adsorption process, and the removal efficiency of chromium (VI) is shown in figure 4. Of note, figure 4 shows that the maximum chromium (VI) removal efficiency (95%) was found at pH 8. It has been reported that when increasing pH from the range of 4 to 7, the removal efficiency of metal ions is increased, which might be because of the formation of negatively charged adsorbent surface (Khaddim *et al.,* 2022). This phenomenon represents the major adsorption process occurs due to electrostatic attraction mechanism. Further increasing the pH above 8, the results show that the removal percentage of chromium (VI) is drastically reduced. Because at the high pH level, the generation of metal hydroxides and the de-protonation of reactive groups on the surface of adsorbent material prevent the adsorption of heavy metals (Shanthi and Selvarajan, 2013; Maity *et al.,* 2022; Gupta *et al.,* 2023).

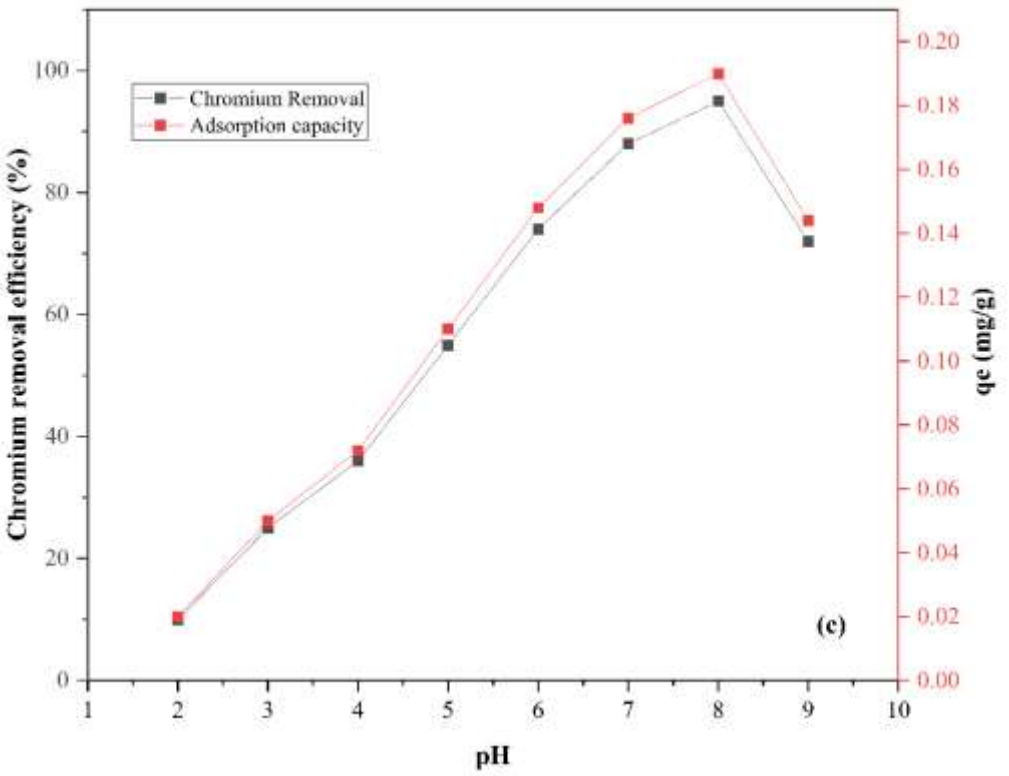


Figure 4. Effect of pH

3.3. Adsorption kinetics

To find out how quickly the adsorption rate occurs, kinetic studies were conducted. Two kinetic models were used namely, pseudo-first-order and pseudo-second-order models, while these models are used to predict the suitable adsorption mechanism. Plotting the graph between log (q_e - q_t) vs t (min) for the adsorption of chromium (VI) ion onto JLP has been used to represent the linearized version of the pseudo-first-order kinetic as shown in figure 5(a), which suggests a less difference in kinetic data from the linearity. The selective parameters, *i.e.*, adsorption capacity (q_e) and rate constant (K_1) associated to the pseudo-first-order kinetics, obtained from intercepts and slopes, and correlation coefficient (R^2) are listed in Table 1. The pseudo-first-order kinetic model was unable to provide an accurate kinetic approximation for the adsorption of chromium (VI) on the JLP, as demonstrated by the correlation coefficient (R^2= 0.8142) and the smaller variation in estimated adsorption capacity. Hence, the pseudo-second-order kinetic model was used to further investigate the experimental results. The pseudo-second-order equation was used to plot the graph between t/qt vs t (min) for the chromium (VI) ion's adsorption onto JLP that has been used to fit the linearized form of the pseudo-second-order as shown in figure 5(b). As compared to first order, the second order equation has significant linearity. The selective parameters, *i.e.*, rate constant (K_2) and

adsorption capacity (q_e) related to the pseudo-second-order kinetics, obtained from intercepts and slopes, and correlation coefficient (R^2) are listed in table 1; the correlation coefficient R^2 = 0.9246. The qe computed and qe observed values are close to being the same, indicating that pseudo-second-order kinetics would provide a better approximation than pseudo-first-order kinetics after the adsorption of chromium (VI) ion onto JLP. The chemisorption process involves electron transfer or sharing between adsorbent and adsorbate, depending upon the functional groups of the type of adsorbent (Niu *et al.*, 2021; Ranasinghe *et al.*, 2018).

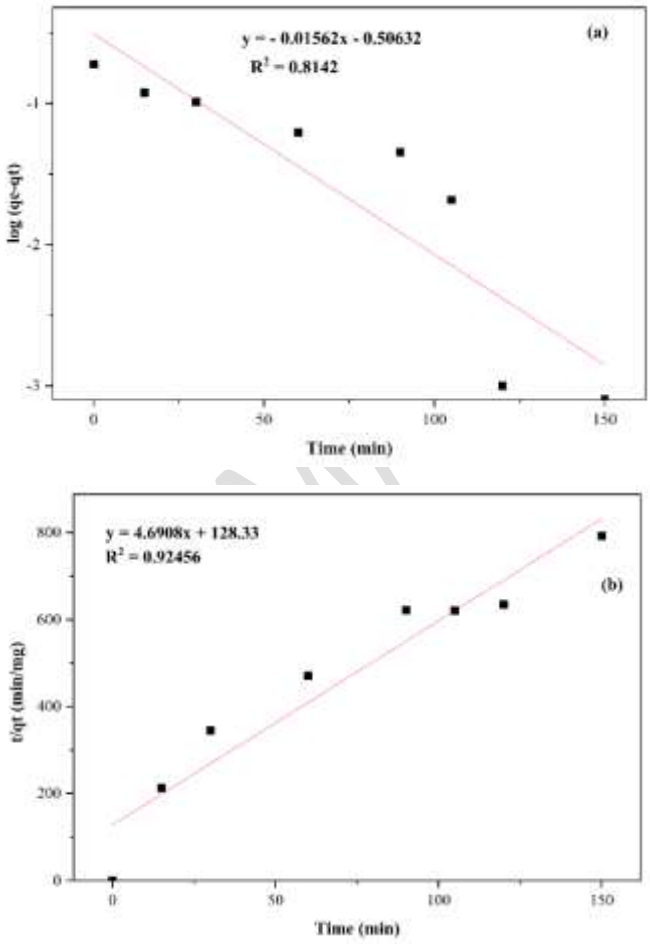


Figure 5. Adsorption kinetic models **a)** pseudo-first-order, **b)** pseudo-second-order for chromium (VI) removal by JLP (adsorbent dose = 0.5 g/L, and pH = 8).

Table 1. Adsorption kinetic parameters for chromium (VI) removal by JLP adsorbent

Kinetics model	Intercept	Slope	Value of constant parameters	R^2
Pseudo-first order	-0.5063	-0.0156	q_e cal. = 0.31167 mg/g; q_e exp = 0.190 mg/g; K_1 = 0.0359 min^{-1}	0.8142
Pseudo-second order	128.33	4.6908	q_e cal. = 0.2132 mg/g; q_e exp = 0.190 mg/g; K_2 = 0.1715 g/mg. min	0.9246

3.4. Isotherm study

The adsorption isotherms were also studied at different dosages of JLP and fitting the results of the Freundlich and Langmuir models are displayed in figures 6(a) and (b). Table 2 shows the fitting parameters and R^2 value. The Freundlich model (R^2 = 0.8191) provides a better fit to the equilibrium adsorption data than the Lang-muir isotherm (R^2= 0.7268). These results show the multilayer coverage of chromium (VI) onto the adsorbent (JLP) heterogeneous surface (Owalude and Tella, 2016). The equilibrium parameter (R_L), which indicates the type of isotherm, is the main characteristic of the Langmuir equation and Freundlich isotherm. The equilibrium parameter (R_L) and adsorption intensity (1/n) (Cherdchoo *et al.,* 2019; Dutta *et al.,* 2022) conditions are as follows:

$R_L > 1$ is unfavourable and used for non-optimum adsorption,

$R_L = 1$ is linear adsorption,

$0 < R_L < 1$ is favourable and used for optimum adsorption

$R_L = 0$ is irreversible adsorption.

1/n = 0 irreversible process

$0 < 1/n < 1$ is optimum adsorption state

1/n > 1 non-optimum adsorption or cooperative adsorption

The obtained result of JLP showed R_L = 0.2412 and 1/n = 0.6558, indicating the favourable optimum adsorption condition.

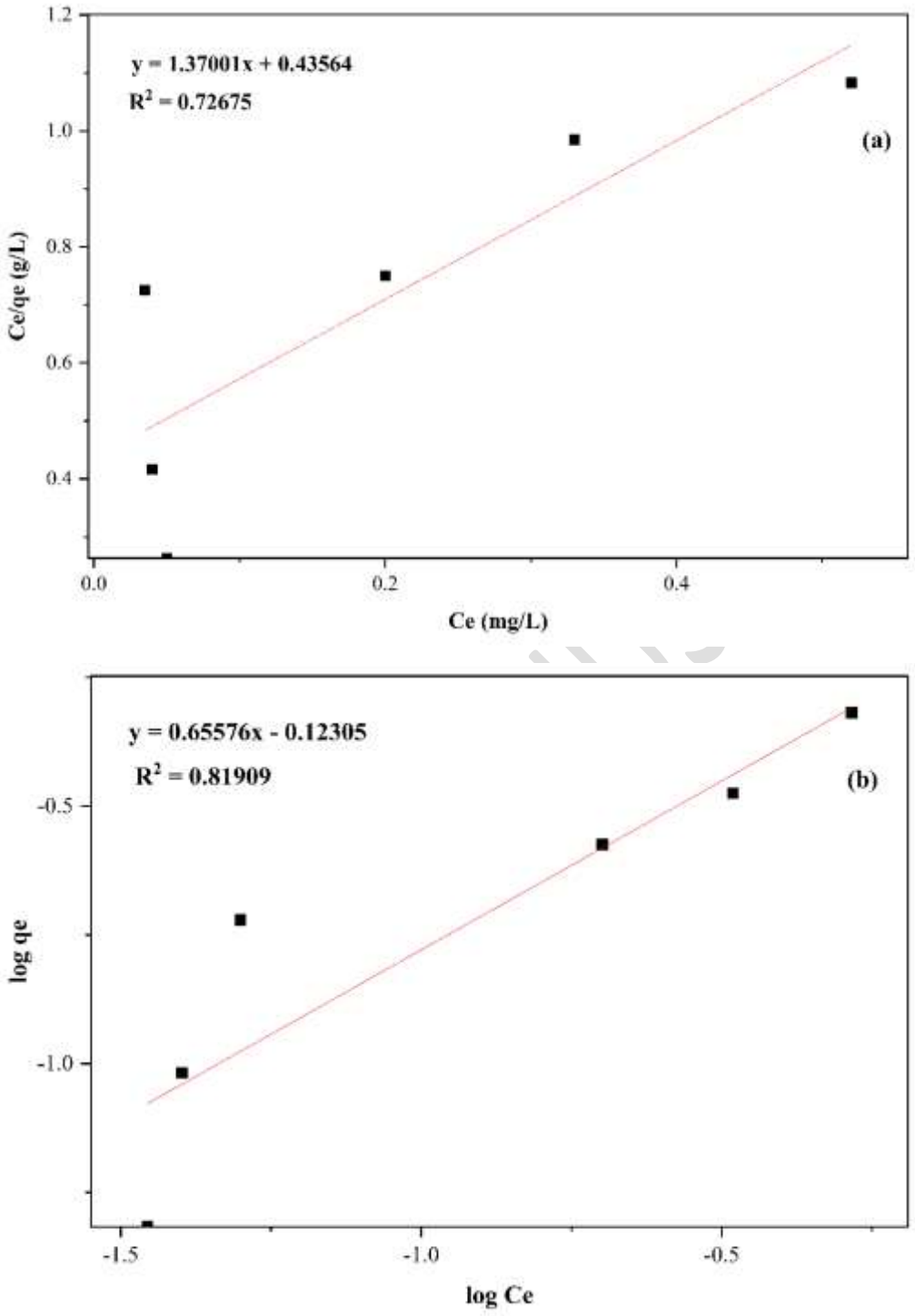


Figure 6. Various isotherm models for chromium (VI) removal by JLP adsorbent, **a)** Langmuir, **b)** Freundlich (adsorbent dose = 0.5 g/L, and pH = 8).

Table 2. Adsorption isotherm **a)** Langmuir and **b)** Freundlich isotherms fitting for the adsorption of Chromium (VI) ion on the JLP

Adsorption isotherm	Value of constant parameters	R^2
a) Langmuir isotherm	q_m = 0.729927007 mg/g; K_L = 3.145087236 L/mg; R_L = 0.2412	0.7268
b)Freundlich isotherm	K_F = 0.7534 mg/g; n = 1.524855; 1/n = 0.6558	0.8191

3.5. Characterization of JLP adsorbent

The scanning electron microscopy (SEM) elucidates the ultrastructure of bio-samples (JLP) in three dimensions, while SEM imagery detects signals such as secondary electrons and backscattered electrons, which are considered main electrons used in biomedical research. The scanning electron micrographs of the fresh and recovered JLP adsorbent are presented in figures 7a and 7b, respectively. The JLP adsorbent possesses coarse spongy structure with good porosity. No significant changes in their morphology and porosity are observed before and after treatment. FT-IR spectroscopy was employed to analyse the changes in functional groups of JLP adsorbent before and after treatment as shown in figure 8. From the figure 8, the result shows that the following peaks 1070, 728, and 613 cm^{-1} are predominant fresh JLP adsorbent (unloaded chromium). When compared with fresh JLP, the recovered JLP (loaded chromium) shows the following peaks: 1618, 1425, 1036, 750, and 580 cm^{-1}. From the IR spectra data, the functional groups ranging from 1600-1400 cm^{-1} shows Aromatic C=C bending and Amine N-H stretching, 1200-1020 cm^{-1} shows Alkoxy C–O stretching, and 750-500 cm^{-1} shows Alkyl C–Br stretching (Mitra and Das, 2019; Nag *et al.*, 2020). The result obtained shows that the major functional groups present in the fresh JLP and the recovered JLP are similar, which represents that the active site presents in the adsorbent shows no significant change in its characteristics.

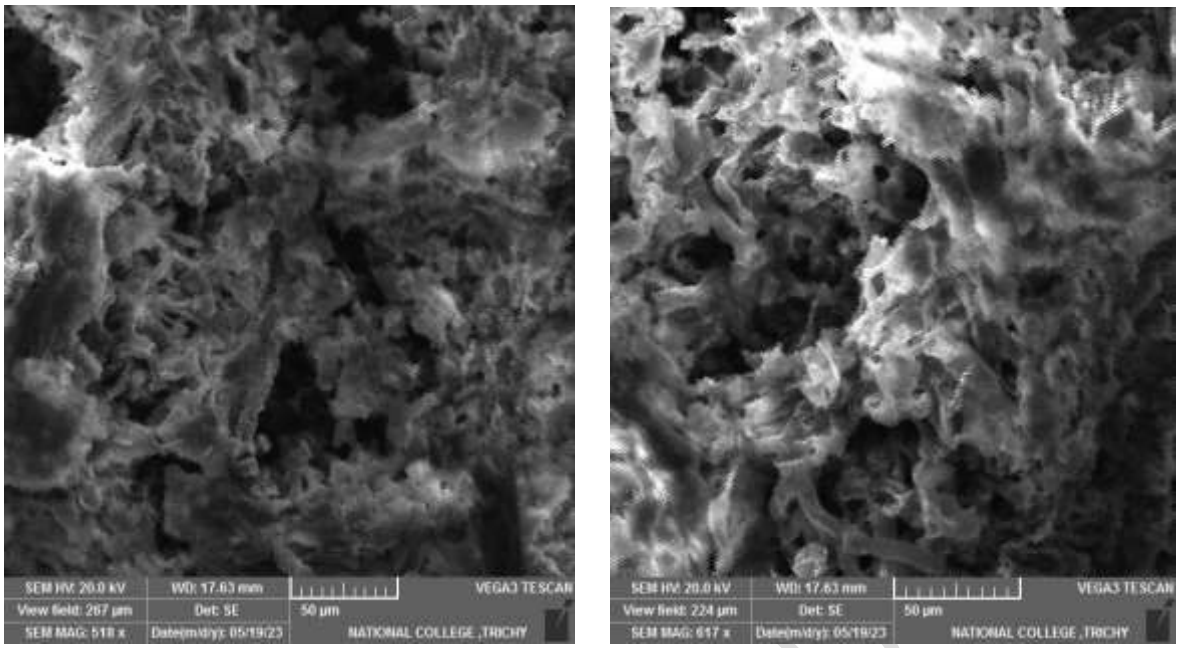


Figure 7. Characteristics of JLP before and after treatment, SEM image of **a)** Fresh JLP **b)** Recovered JLP

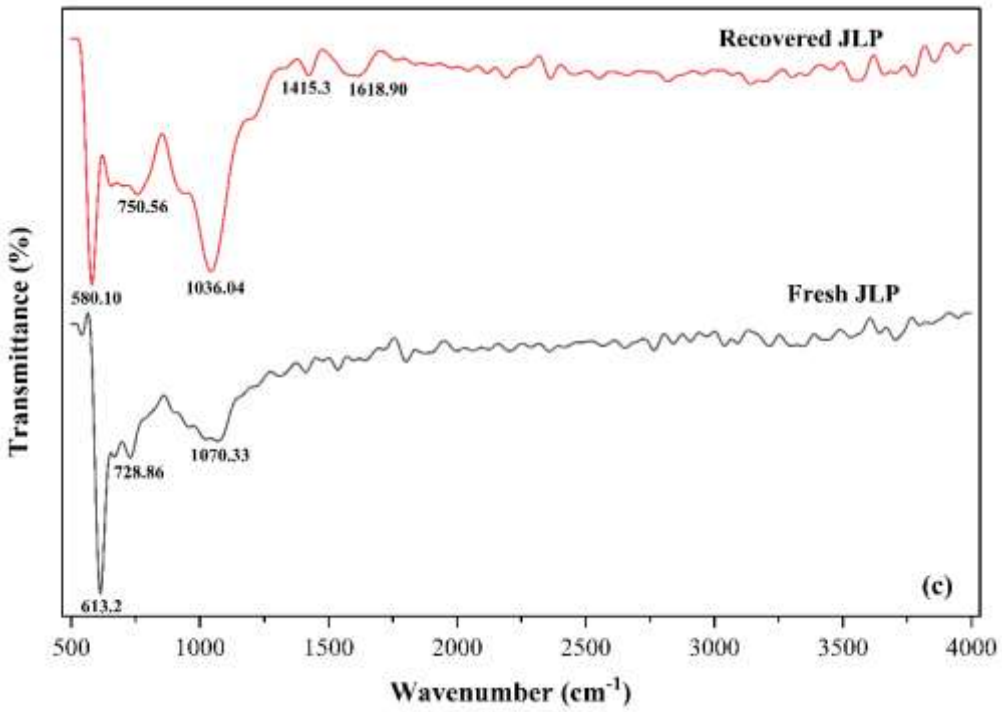


Figure 8. FT-IR of the adsorbent (JLP); FTIR spectrum (Experimental conditions: initial pH = 8., JLP Dose = 0.5 g/L, Reaction time = 120 min).

3.6. Recovery of chromium using a desorption study

While discussing the potential uses, the commercial applications of chromium (VI) include corrosion inhibition, glassware-cleaning solutions, plating, wood preservatives, metal finishing, among others (Barceloux and Barceloux, 1999). In the present study, we performed experiments demonstrating the chromium (VI) recovery from the adsorbent (jackfruit leaves).

The desorption process serves essential for regenerating and reusing those used adsorbents (Zhou et al, 2019). Desorption study is also indispensable to recover the adsorbed compound/s, reduce waste, and sustain a minimal process cost (Zhou et al, 2019). The desorption study was carried out by shaking 0.1 g of JLP adsorbent which is adsorptive to chromium (VI) ion with different concentrations of HCl and HNO3 (0.1M, 0.5M and 1M of HCl and HNO3) at 25 °C for 60 min. A clear solution containing the desorbed chromium (VI) were obtained by centrifugation, separating the JLP adsorbent. The concentration of desorbed chromium (VI) ion was determined spectrophotometrically (Ali et al., 2021). Figure 9 shows the recovery % of chromium (VI) using HCl and HNO_3 at various concentrations. The results as shown in figure 9 revealed the higher recovery % of chromium (VI) at 0.5 M HCl (90%) as compared to 0.5 M HNO_3 (87%).

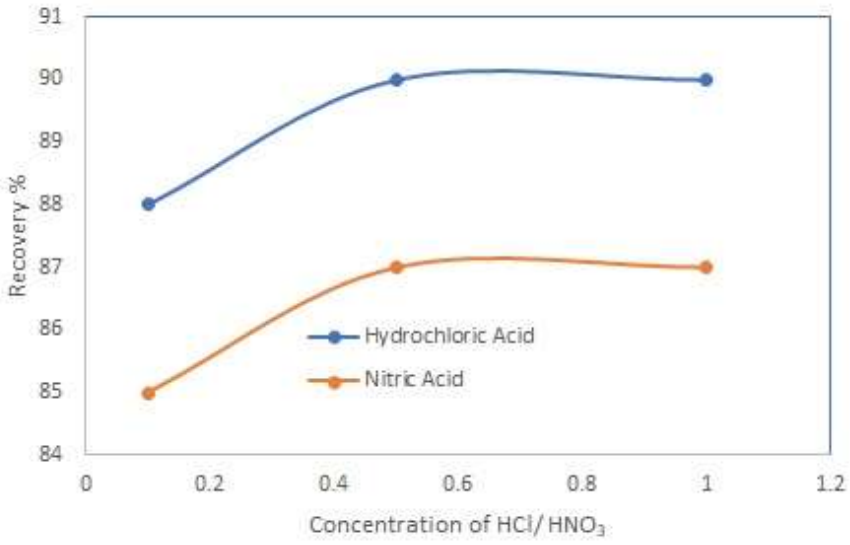


Figure 9. Desorption study for chromium (VI) recovery

3.7. Cost analysis

Removal of heavy metals from landfill leachate on a commercial scale is highly dependent on the cost of adsorbent and its production. Our study aims to remove chromium (VI) from landfill leachate using Jackfruit leaves (*Artocarpus heterophyllus*), which is a very common tree in India and is widely available throughout the country. The cost of procurement of the adsorbent raw material employed in the present study, *i.e.* jackfruit leaves, can be considered negligible. Moreover, the production cost of the adsorbent (jackfruit leaves) comprises of numerous steps, including the preparation and characterization of adsorbent, and its reusability. This would be comparatively very nominal relative to existing methodologies.

4. Concluding remarks

In the present study, a batch system was used to examine the adsorption capacity of JLP to remove chromium (VI) from landfill leachate. The effects of experimental factors such as pH, contact time, and adsorbent dose on the chromium (VI) removal percentage were investigated. The results of the experimental studies have apparently demonstrated the chromium (VI) removal efficiency of JLP. The optimum values of JLP loading, adsorption time, and pH were 0.5 g/L, 120 min, and 8, respectively. The Langmuir model revealed that JLP had a maximum monolayer and Freundlich isotherm, displaying non-homogeneity of the adsorbent surface and multilayer adsorption. There was no significant resistance from the film diffusion, and the adsorption kinetics followed a pseudo-second-order kinetic model. Moreover, JLP had a number of other benefits that make it a suitable adsorbent for the removal of chromium (VI) from landfill leachate, including its low cost, eco-friendly and wide availability. Taken together, this study suggests that JLP may be employed as a bio-adsorbent for the removal of toxic heavy metals like chromium (VI) from the contaminated soil and water resources. Additional studies can be conducted using physico-chemical bio-adsorbent to treat various industrial effluents for the removal of heavy metals. Furthermore, studies are needed to investigate the effects of temperature variations on the adsorption process. Additionally, exploring the potential of a continuous adsorption process could provide valuable insights into the scalability and long-term viability of this method.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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