Decontamination of cadmium(II) from synthetic wastewater onto shea fruit shell biomass

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Abstract

Shea fruit shells being an agricultural waste material was utilized to test its novelty as an inexpensive biosorbent for the elimination of Cd(II) from synthetic wastewater using the batch method. A batch study was employed to probe the impact of pH of the solution, contact time, temperature and initial concentration on the depollution of Cd(II) ions using unmodified Shea fruit shells biomass. The decontamination of Cd(II) by the unmodified Shea fruit shells biomass was found to be dependent on these adsorption parameters. The equilibrium data best represented Freundlich isotherm by a correlation coefficient (R^2) of 0.9691. The kinetic models analyzed suggest pseudo-second-order ($R^2 = 0.9515$) as the best fit model signifying that the removal of Cd(II) ions was on account of chemisorption. The positive values of the thermodynamic parameters, ΔH° and ΔS° reveal endothermic and increase of disorder of the process while the negative charge of ΔG° shows spontaneity of the system.

Keywords Biosorption · Equilibrium · Heavy metals · Kinetics · Thermodynamics

Introduction

Pollution by heavy metals in the natural environment has become a universal concern owing to their enduring and noxious effects on organisms when ingested beyond a certain concentration (Krika et al. 2016). Lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), nickel (Ni), copper (Cu) and mercury (Hg) are heavy metals that originate from battery manufacturing, petroleum refining, metal plating, paint manufacturing and mining activities (Njikam and Schiewer 2012).

Cadmium compounds are used in rechargeable Cadmium–Nickel (Cd–Ni) batteries, alloys, pigments, electronic compounds and stabilizers for polyvinyl chloride (Wuana and Okieimen 2011). Cadmium moves into the aquatic environment by dint of industrial effluent of Cadmium–Nickel batteries, mining, metal plating industries and metal alloys

(Krika et al. 2016). Cadmium can be inherent in the system for several years and has been ranked as the seventh most lethal metal and frequently present in battery manufacture, cement production, steel production and phosphate fertilizers (Ad et al. 2015). The detrimental effect of cadmium noxiousness in a human comprises pains in bones, impairment of the kidney in addition to its carcinogenic, teratogenicity and mutagenic effects (Emenike et al. 2016). Also, cadmium poisoning results in hypertension, testicular tissue damage, destruction of red blood cells, fishes and several marine species (Rao et al. 2011; Pfafflin and Zigler 2006).

Recently, many studies concluded that cadmium remains non-biodegradable when ingested into living systems and its circulation through the ecosystem is indestructible (Mutlu et al. 2012; Kumar et al. 2011). Cadmium exposure happens primarily through ingestion and inhalation and once it enters into the bloodstream, the erythrocytes transport it and at the intracellular phase, cadmium is engrossed to a portion of protein (Godt et al. 2006). Industrial effluents containing cadmium contaminants reach organisms via nutrition and become detrimental through bioaccumulation (Alfarra et al. 2014). The excessive exposure of cadmium to the human system has the tendency of being accumulated in the liver and renal cortex and consequently reallocates to the kidney during metallothionein production in the liver (Satarug et al. 2010). Åkesson et al. (2008) indicate that the kidneys

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accumulate 50% of cadmium load, 20% found in the muscles and the liver contains about 15%. The acceptable limit of Cd(II) in potable aquatic sources is $5.00 \mu\text{g/L}$ according to European Union Standards. However, the concentration of cadmium in safe water sources is usually $< 1.00 \mu\text{g/L}$ (Emenike et al. 2016).

The lives of humans could be made easy and comfortable through the decontamination of toxic heavy metals and keeping their concentration within tolerable values in drinking water using suitable treatment methods. Among these treatment techniques is the use of chemical reagents to precipitate metal ions from solution (Bayuo et al. 2018b; Meunier et al. 2006). Other methods applied in the field of water treatments are solvent extraction, coagulation–flocculation, membrane separation, electrocoagulation, cementation and ion exchange adsorptions (Bayuo et al. 2020). However, each of these methods formally used has its merits and limitations in applications such as the large volume of chemicals, tedious, high capital investments and consumes time.

In line with this, several new approaches and techniques have been investigated to develop effective methods to eliminate poisonous metals from aqueous media. Adsorption through commercial activated carbon has the capability of removing metals from inorganic effluents. However, commercial activated carbon is expensive but it has been used with great success because of its bulky surface area and reactivity (Krika et al. 2016). Attributable to the expensiveness of commercial adsorbents, several new approaches have been developed to decontaminate metals from wastewater by natural adsorbents. Many studies have indicated that the safest, easiest and most cost-effective method to depollute disastrous metals from effluents of industries is adsorption by natural biomass. Among others are groundnut husk (Bayuo et al. 2019a, b), cork powder (Krika et al. 2016) and sesame waste (Cheraghi et al. 2015).

Shea fruits grow on the African Shea tree also known as the Shea butter or Shea nut tree (*Vitellaria paradoxa*). Shea fruits are typically gathered and processed by locals and provide an important source of income for the people of the African sub-Saharan savanna. The fruits contain a relatively large and oily nut, used to make Shea butter while the fruit shells are usually thrown away or serve as a source of fuel.

Hence, in the current study, unmodified Shea fruit shells have been tested in the decontamination of Cd(II) from synthetic aqueous solutions.

Materials and methods

Preparation of the adsorbent

The Shea fruits were collected from a farm located at Pungu, Navrongo in the Upper East region of Ghana. The Shea

fruits were treated with distilled water to thoroughly get rid of any contaminant. The shells were then removed and placed in an oven to dry at a temperature of 110°C to a consistent mass and ground into powder form. Lastly, the powder was sieved by different mesh sizes ranging from 0.50–1.00 mm of particle size. The sample prepared was stored in airtight polythene bags and used for the batch adsorption tests.

Preparation of Cd(II) ion solution

Chemicals of analytical reagent grade and distilled water were utilized during the experimentations. A 2.672 g of cadmium nitrate $[\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}]$ was dissolved in a volumetric flask with 200 mL distilled water and subsequently topped up to a 1000-mL mark of the volumetric flask to obtain a stock solution of 1000 mg/L Cd(II). The bench solutions were prepared through serial dilution of the stock Cd(II) solutions by the distilled water. The pH of the initial aqueous solutions was adjusted by 0.10 M HCl and NaOH.

Batch experiments

The elimination of Cd(II) ions onto unmodified Shea fruit shells was explored by batch mode.

The required amount of unmodified Shea fruit shells (UMSFS) biomass was agitated with 100 mL solutions of Cd(II) of desired concentration in 250-mL flasks on a magnetic stirrer at 250 rpm. The mixture was filtered with Whatman 40 filter paper after agitation time was achieved and the amount of Cd(II) in the filtrate was obtained by the Spectrometry method [Atomic Absorption Spectrophotometer (AAS), NovAA 400p model]. The detection of Cd(II) concentrations was performed three times and readings of blank were taken from all the measurements.

The percentage decontamination and the Cd(II) ions adsorbed per unit mass of UMSFS at equilibrium time was evaluated by Eqs. (1) and (2), respectively (Bayuo et al. 2018b).

$$\text{Removal efficiency}(\%) = (C_o - C_e/C_o) \times 100 \quad (1)$$

where C_o and C_e are Cd(II) initial and equilibrium concentrations (mg/L), respectively.

$$q_e = (C_o - C_e/m) \times V \quad (2)$$

where q_e denotes Cd(II) ions adsorbed per unit mass of UMSFS at equilibrium time, V and m are the solution volume (mL) and UMSFS mass (g), respectively.

Effect of contact time

Batch mode tests were performed by varying contact time and maintaining a constant solution pH, UMSFS particle

size, UMSFS dosage, initial Cd(II) concentration and solution temperature. The adsorbent was agitated at different times (15.00–180.00 min) with the adsorbate solutions. The required flasks containing the adsorbent–adsorbate mixtures were filtered and the Cd(II) concentration was measured by the means of AAS.

Effect of initial pH of the solution

The impact of the initial pH of solution on the sorption of Cd(II) was explored by adding 100 mL of Cd(II) solution in a flask. The desired initial pH of the aqueous solutions (2.00–13.00) was controlled by 0.10 M of HCl and NaOH solutions using a portable pH meter. Independent variables like equilibrium contact time, UMSFS particle size, UMSFS dosage, initial Cd(II) concentration and solution temperature remained unchanged during the experiments. After equilibrium time, the Cd(II) concentration was measured by AAS and the sorption rate was calculated.

Effect of initial Cd(II) concentration

The influence of Cd(II) initial concentration was conducted by way of performing the adsorption experiments at an altered concentration of Cd(II) alternating from 10.00–50.00 mg/L. The additional variables such as equilibrium time, optimum pH of the solution, UMSFS particle size, UMSFS dosage and temperature were kept constant. The adsorbent–adsorbate solution was stirred and after the optimum time, the concentration of Cd(II) in the filtrate after filtration was measured by AAS.

Effect of solution temperature

The batch mode tests were executed at five (5) diverse solution temperatures (25.00–60.00 °C) using a magnetic stirrer with a heater. The reliability of the solution temperature was conserved with a precision of $\pm 0.50^\circ\text{C}$ and parameters like optimum agitation time, solution pH, UMSFS particle size, UMSFS dosage and initial Cd(II) concentration were kept constant. The Cd(II) concentration in the sample solutions was measured by AAS after the equilibrium time was accomplished.

Results and discussion

Effect of contact time

The results obtained from the impact of contact time by batch experiments are depicted in Fig. 1. Figure 1 revealed that the removal of Cd(II) from synthetic wastewater increased with increasing contact time. It was found that

Fig. 1 Effect of contact time on the adsorption of Cd(II) ion onto UMSFS biomass

during the early stage, Cd(II) removal was rapid and later plateau until equilibrium was reached. This may probably indicate that there was a large initial concentration gradient between the Cd(II) ions in solution and accessible adsorption sites on the UMSFS surface (Bayuo et al. 2019b).

The UMSFS achieved maximum adsorption (76.86%) of Cd(II) at about 150 min of contact time. Therefore, for all the other adsorption tests, 150 min was used as the equilibrium shaking time. The equilibrium time obtained in the current study is longer than those usually utilized for the adsorption of Cd(II) by other low-cost adsorbents. Among them include isolated green algae (Kumar et al. 2018); cork biomass (Krika et al. 2016); sponge gourd (Ad et al. 2015); Kaolinite and Metakaolinite clay (Essomba et al. 2014); sesame (Chen et al. 2011); maize stalks (El-Sayed et al. 2011).

Effect of initial pH of the solution

The sorption of heavy metals has been found to show dependence on the pH of the solution caused by its effect on the adsorbent surface charge, degree of ionization and adsorbent species (Ghoneim et al. 2014). The Cd(II) removal percent by UMSFS augmented with increasing initial pH of the solution as presented in Fig. 2. At higher pH, fewer hydrogen ions were surrounded by the adsorbent thereby allowing Cd(II) to bind to accessible sorption locations of the adsorbent and maximum Cd(II) removal (74.06%) was achieved by pH of 5.0. However, at a small initial pH, the hydrogen ions undergo an active competition with Cd(II) ions for the number of vacant sorption locations on the adsorbent surface (Bayuo et al. 2019b; Ghoneim et al. 2014).

Cheraghi et al. (2015) conducted batch adsorption experiments to remove Cd(II) in the pH range of 2.0–9.0 while other parameters remained constant. The study shows that the best pH value was 6.0 and the removal efficiency of Cd(II) was found to increase from 33.45 to 92.95% with increasing pH value from 2.0–6.0. Subsequently, with

Fig. 2 Effect of pH of solution on the adsorption of Cd(II) ion onto UMSFS biomass

increasing pH value above 6.0, the percent removal of Cd(II) ions declined. Similarly, Essomba et al. (2014) varied pH between 3.0–10.0 to remove Cd(II) from aqueous solution using Kaolinite and Metakaolinite clay. It was found that at pH values higher than 8.0 insoluble cadmium hydroxide starts, precipitating from the solutions making true sorption studies impossible.

Effect of Cd(II) initial concentration

The influence of preliminary concentration on depolluting Cd(II) from the synthetic wastewater by UMSFS is depicted in Fig. 3. The sorption experimentations were investigated at 1.50 g/L UMSFS dosage and initial solution pH of 5.0 under room temperature. Figure 3 reveals that the metal ions removal by UMSFS showed dependence on the initial molarity of Cd(II). At lower preliminary Cd(II) molarity, Cd(II) removal was higher than the higher initial amount of Cd(II). This may be because at a higher initial amount of

Fig. 3 Effect of initial concentration on the adsorption of Cd(II) ion onto UMSFS biomass

Cd(II), the available sorption sites on the UMSFS surface become saturated (Bayuo et al. 2019b). Similarly, El-Sayed et al. (2011) found that the percentage removal of Cd(II) decreased with increasing the initial metal ion concentration.

The optimal Cd(II) initial molarity determined in the present study is 10.00 mg/L with a percentage removal of 71.00%. This maximum initial concentration of Cd(II) is consistent with the finding of Ghoneim et al. (2014) and Yang, (2011) where, 99.60% and 96.70% removal of Cd(II) ions were achieved at 10.00 mg/L and pH of 5.5 and 12.0 using marine green algae and bentonite, respectively.

Effect of temperature

Generally, the sorption process is highly dependent on the temperature of the solution. The influence of solution temperature on Cd(II) elimination was carried out at variable temperatures and maintaining other parameters constant. The removal efficiency of Cd(II) by UMSFS was improved from 25.00% to 62.93% until at about 40 °C, where optimum removal (66.93%) of Cd(II) was attained as presented by Fig. 4. The increase in removal efficiency of Cd(II) with increasing temperature might be because of the increasing diffusion rate of the solute across the outer periphery layer and subsequent adsorption onto the sorbent surface (Ghoneim et al. 2014). The attainment of Cd(II) maximum adsorption at higher temperatures by the UMSFS could describe the adsorption process to be due to chemisorption and endothermic (Bayuo et al. 2019b).

The finding of the effect of temperature in this study is similar to the results obtained by Mopoung and Kengkhetkit (2016) using NaOH treated pineapple waste. It was suggested that the higher temperature improves the trend by either increasing the number of available active sites or

Fig. 4 Effect of temperature on the adsorption of Cd(II) ion onto UMSFS biomass

decreasing the thickness of the boundary layer surrounding the adsorbents (Nguyen et al. 2013).

Equilibrium adsorption isotherms

In the determination of a best-fit model for designing the adsorption system, equilibrium isotherm data are usually analyzed by fitting into isotherm models (Othman et al. 2011). The adsorption capacity of UMSFS biomass was determined by fitting Cd(II) equilibrium data to Langmuir and Freundlich isotherms.

Langmuir isotherm model

The Langmuir model presumes that metal ions removal occurs on a homogenous sorbent surface by monolayer sorption without interaction among adsorbed ions (Bayuo et al. 2019a). The Langmuir model is often applied in the description of the optimal sorption rate of biosorbent and it is the utmost significant factor for the sorption process. It is expressed as given in Eq. (3) (Bayuo et al. 2018a):

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

where C_e and q_e are Cd(II) concentration (mg/L) and adsorption capacity (mg/g) at equilibrium time, respectively. The constants q_m (mg/g) and K_L (L/mg) are associated with uptake capacity and net sorption enthalpy, respectively. The constants q_m and K_L are obtained by plotting $\frac{C_e}{q_e}$ versus C_e (Fig. 5) with a gradient; $\frac{C_e}{q_m}$ and intercept; $\frac{1}{q_m K_L}$.

The results of the equilibrium isotherm studies presented in Fig. 5 affirmed that the equilibrium data show good agreement with the Langmuir model with a determination coefficient (R^2) of 0.8829 and monolayer adsorption capacity of 25.4453 mg/g as summarized in Table 1. The Langmuir fit is consistent with strong monolayer and homogeneous Cd(II)

Fig. 5 Langmuir adsorption isotherm plot of Cd(II) ion onto UMSFS biomass

Table 1 Langmuir and Freundlich model constants for Cd(II) sorption by UMSFS biomass

Model	Parameter	Value
Langmuir	q_m (mg/g)	25.4453
	K_L (L/mg)	0.0302
	R_L	0.4484
	R^2	0.8829
Freundlich	K_F (mg/g)	0.3371
	n	2.1739
	$\frac{1}{n}$	0.4600
	R^2	0.9691

sorption onto specific sites on the UMSFS biomass (Bayuo et al. 2019b).

Additionally, the indispensable feature of the Langmuir model is expressed in relation to a dimensionless coefficient separation variable (Bayuo et al. 2019b):

$$R_L = \frac{1}{1 + K_L C_0} \quad (4)$$

where R_L and K_L are variable of separation and Langmuir constant (L/mg), respectively, while C_0 is initial adsorbate molarity (mg/L). The value of R_L (0.4484) attained during Cd(II) decontamination by UMSFS biomass is between 0 and 1 implying a suitable sorption process (Bayuo et al. 2019a). Thus, the experimental data exhibited efficient Cd(II) removal by UMSFS biomass in this study.

Freundlich isotherm model

The Freundlich empirical isotherm is applicable for demonstrating sorption on heterogeneous biosorbent surfaces. The linearized form of the Freundlich model is given by Eq. (4) (Bayuo et al. 2018b).

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \quad (5)$$

where C_e and q_e are Cd(II) concentration (mg/L) and adsorption capacity (mg/g) at equilibrium time, respectively. The constant K_F and n are relative sorption ability (mg/g) and intensity of the biomass, respectively. By plotting $\log q_e$ against $\log C_e$ (Fig. 6), the coefficients n and K_F are determined from the gradient; $\frac{1}{n}$ and intercept; $\log K_F$, respectively.

The results of Fig. 6 showed that Cd(II) equilibrium data represented Freundlich isotherm well than that of the Langmuir by a determination coefficient of 0.9691. This implied that Cd(II) biosorption occurred on the heterogeneous surfaces of UMSFS biomass (Bayuo et al. 2019a). Moreover, in Table 1, K_F is 0.3371 implying Cd(II) maximal sorption capacity by UMSFS (Ghoneim et al. 2014) and the value of $\frac{1}{n}$

Fig. 6 Freundlich adsorption isotherm plot of Cd (II) ion onto UMSFS biomass

(0.4600) lies between 0 and 1 suggesting sufficient sorption (Bayuo et al. 2018a).

The better fitness of the Freundlich model to the equilibrium data than that of the Langmuir model conforms to the results of Sukpreabprom et al. 2014 who investigated the removal of Cd(II) using bottom ash. However, the findings of this study contradict other studies carried out to remove Cd(II) using cheap biosorbents in which the Langmuir model shows a dominant fit to the experimental data (Habte et al. 2020; Kumar et al. 2018; Kabir et al. 2015).

Equilibrium adsorption kinetics

The speed upon which adsorption takes place plays a major role in planning batch technique tests. Therefore, it is important to determine the sorption kinetics that can confirm the exploration of the superlative model that could describe the kinetic data well. The present study applied pseudo-first and pseudo-second-order kinetic models to simulate Cd(II) experimental data by UMSFS biomass.

Pseudo-first-order kinetic model

The pseudo-first-order kinetic model is generally used globally for the projection of sorption tests of metal ions. The linearized form is expressed in Eq. (6) (Bayuo et al. 2020).

$$\log(q_e - q_t) = \log q_e - \frac{k_{p1}}{2.303} t \quad (6)$$

where k_{p1} (min^{-1}) is rate constant of pseudo-first-order, q_e and q_t (mg/g) are equilibrium and specific time (min) sorption rates, respectively.

The plot of $\log(q_e - q_t)$ versus t of the pseudo-first-order model is depicted in Fig. 7.

Fig. 7 Pseudo-first-order plot of Cd(II) onto UMSFS biomass

Pseudo-second-order kinetic model

It has been established that the pseudo-second-order model has been explored extensively to elucidate inorganic and organic compounds adsorption on different biosorbents and formulated in the form (Bayuo et al. 2020):

$$\frac{t}{q_t} = \frac{1}{k_{p2} q_e^2} + \frac{1}{q_e} t \quad (7)$$

where k_{p2} ($\text{gmg}^{-1}\text{min}^{-1}$) is the rate constant of pseudo-second-order, q_e and q_t (mg/g) are equilibrium and specific time (min) sorption rates, respectively. The pseudo-second-order model plot is given as $\frac{t}{q_t}$ versus t as presented in Fig. 8.

From the kinetic model plots, the various model constants and correlation coefficients were calculated as summarized in Table 2. The correlation coefficients of the pseudo-first and pseudo-second-order kinetic equations were 0.9146 and 0.9515 as illustrated in Figs. 7 and 8, respectively. The higher correlation coefficient of the pseudo-second-order kinetic equation suggests that the equilibrium data have shown a good representation of the model (Bayuo et al. 2020, 2018b). The agreement of the equilibrium data to the pseudo-second-order equation implies that Cd(II) decontamination by UMSFS biomass may be due to chemical adsorption and hence, the rate-limiting step. Furthermore,

Fig. 8 Pseudo-second-order plot of Cd(II) onto UMSFS biomass

Table 2 Kinetic model constants and their correlation coefficients (R^2) for Cd(II) removal by UMSFS biomass

Kinetic model	Parameter	Parameter value
Pseudo-first-order	$K_{p1}(\text{L/min})$	0.0440
	$q_e(\text{mg/g})$	0.0277
	R^2	0.9146
Pseudo-second-order	$K_{p2}(\text{L/min})$	0.0008
	$q_e(\text{mg/g})$	30.7692
	R^2	0.9515

the closeness of the correlation coefficient values of the pseudo-first and pseudo-second-orders kinetic equations shows that the sorption system adopted an intra-particle diffusion model with one or more mechanisms influencing the sorption system (Cheraghi et al. 2015).

The good conformity of the pseudo-second-order model to the equilibrium data in comparison to the pseudo-first-order model is similar to the findings of several studies conducted to remove Cd(II) with other cheap biosorbents (Kumar et al. 2018; Krika et al. 2016; Ad et al. 2015; Cheraghi et al. 2015; Othman et al. 2011).

Adsorption thermodynamic studies

Enthalpy, entropy and Gibbs free energy are the thermodynamic parameters that should be evaluated before the spontaneity of the system can be inferred. Gibbs free energy (G^0) is regarded as the spontaneity indicator of a chemical reaction (Ho and Ofomaja 2006). The Gibbs free energy (ΔG^0) of sorption can be written in relation to Langmuir adsorption constant by the equation (Krika et al. 2016):

$$\Delta G^0 = -RT \ln K_L \quad (8)$$

The Gibbs free energy change (ΔG^0) is linked to the change in enthalpy (ΔH^0) and entropy (ΔS^0) under constant temperature as expressed in Eq. (9).

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (9)$$

Combining Eqs. (8) and (9) yields Eq. (10):

$$\ln K_L \frac{\Delta S^0}{R} = \frac{\Delta H^0}{RT} \quad (10)$$

where R denotes the ideal gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$), K_L represents the distribution coefficient for the adsorption (mL g^{-1}) and T (K) signifies absolute solution temperature. The values of ΔH^0 and ΔS^0 are obtained from $\frac{-\Delta H^0}{R}$ (slope) and $\frac{-\Delta S^0}{R}$ (intercept) by plotting $\ln K_L$ versus $1/T$.

The experimental data of the thermodynamics study reveals that the ΔG^0 ($-2.7702 \text{ kJ mol}^{-1}$) of the sorption system is negative indicating the feasibility and spontaneous nature of Cd(II)

biosorption by the UMSFS biomass. The positive value of ΔH^0 ($32.7634 \text{ kJ mol}^{-1}$) indicates chemisorption and endothermic nature of the sorption system while the positive value of ΔS^0 ($0.1135 \text{ kJ K}^{-1} \text{ mol}^{-1}$) shows an increase of disorder at the solute–solvent interface for the period of Cd(II) depollution by the UMSFS biomass (Krika et al. 2016). The results of the thermodynamic studies conformed to the results of Bulut and Tez (2007) who investigated the decontamination of Pb(II), Ni(II) and Cd(II) from aqueous media using sawdust. The thermodynamic variables evaluated in their study confirm the spontaneity and endothermic nature of the sorption procedure.

Conclusion

Batch adsorption studies were conducted using UMSFS biomass to eliminate Cd(II) from synthetic wastewater. The study indicates the adsorbent's suitability to eliminate Cd(II). Therefore, when considering the economic aspects of wastewater treatment, the selected adsorbent is recognized as a valuable material.

The biosorption rate of Cd(II) onto the UMSFS biomass shows dependence on the independent sorption variables (factors). For instance, the removal efficiency was improved with rising agitation time until equilibrium time was attained at 150 min. The sorption process was favored by increasing the pH of the initial solutions. The optimal initial solution pH was accomplished at a pH of 5.0 with 74.06% Cd (II) removal. Furthermore, Cd(II) biosorption was higher at low-level Cd(II) molarity and maximum Cd(II) uptake was at 10.00 mg/L. More so, Cd(II) decontamination was enhanced by intensifying solution temperature until the equilibrium sorption state was achieved at 40 °C.

The equilibrium isotherm and kinetic studies reveal good fitness of the equilibrium data to Freundlich isotherm and pseudo-second-order kinetic models.

The positive enthalpy and entropy values implied endothermic (chemisorption) and an increase of randomness during the sorption process. The negative ΔG^0 value reflects the feasibility and spontaneous nature of the system.

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Declarations

Conflict of interest The author reports no conflict of interest.

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