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Biosorption of zinc metal ion in aqueous solution using biowaste of *Pithophora cleveana* Wittrock and *Mimusops elengi*

G. Kalyani[a,*], R. Gokulan[b,*], S. Sujatha[c]

[a]*Department of Chemical Engineering, GMR Institute of Technology, Rajam, Srikakulam, Andhra Pradesh – 532 127, India, emails: kalyani.gaddam@gmail.com/kalyani.g@gmrit.edu.in*
[b]*Department of Civil Engineering, GMR Institute of Technology, Rajam, Srikakulam, Andhra Pradesh – 532 127, India, email: gokulravi4455@gmail.com*
[c]*Department of Civil Engineering, K. Ramakrishnan College of Technology, Trichy, Tamil Nadu – 621 112, India, email: sujalalit@gmail.com*

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ABSTRACT

A freshwater algae *Pithophora cleveana* Wittrock and a tree leaf of *Mimusops elengi* were used as a biosorbent for the removal of zinc metal ions from the aqueous solution in batch mode operation. The optimum parameters namely solution pH, contact time, particle size, adsorbent dosage, and temperature were studied. Adsorption isotherm models namely Langmuir, Freundlich, Temkin, Dubinin–Radushkevich (D–R) were studied along with kinetic models namely pseudo-first-order, pseudo-second-order, intraparticle diffusion, and Elovich model. Further, to understand the adsorption mechanism characterization of adsorbent were analyzed using a scanning electron microscopy, Fourier transforms infrared, and X-ray diffraction. The thermodynamic study concluded that the reactions are spontaneous and exothermic. The maximum removal of 74.11% and 73.11% was obtained for *P. cleveana* Wittrock and *M. elengi* biosorbent with a maximum uptake of 13.58 and 12.96 mg/g.

Keywords: Biosorption; *Mimusops elengi*; Modeling; *Pithophora cleveana* Wittrock; Zinc

1. Introduction

An increase in population and rapid industrialization resulted in an enormous amount of waste generation to the environment. This waste when mixed with the surface water or percolates into the soil to reach groundwater will result in water pollution. Water is the main source of all living beings, and if the quality of the water is degraded, it will become a huge problem for the human and the environment. This polluted water when consumed without treatment will cause many side effects to human health and aquatic life. Many industries liberate different types of pollutants and it may be heavy metal, pesticides, or dyes [1–3]. Of these type of pollutants, heavy metals are a serious concern, since heavy metals affect the ecosystem, agriculture, and human health vigorously. Nuclear industries, chemical industries, mining, and metallurgy industries play a very important role in the release of heavy metal ions into the environment [4,5].

Zinc is an essential compound that is required for the growth of plants, animals, and humans, but when consumed in excess it will cause serious illnesses like skin allergy, vomiting, stomach problem, and anemia [6]. Excess zinc that is present in the surface water or groundwater is maybe the waste coming from battery manufacturing, fertilizing, and electroplating process. This excess zinc is non-biodegradable and enters into the food chain of the ecosystem. So as like other heavy metals, zinc is also a

* Corresponding authors.

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serious metal that needs to be removed from the industries before it is mixed with the surface water. The removal of zinc also becomes a critical challenge to the researcher to remove at low cost [7].

Traditionally many methods like ion exchange, precipitation, chemical oxidation, reduction, electrochemical method, solvent extraction, and membrane filtration were used for the removal of heavy metals [8]. However, these treatment methods are not effective in the removal of zinc, and the cost associated with these methods is very high with low removal efficiency is obtained when a large quantity of wastewater is treated [9]. Many researchers pointed out that adsorption is one of the best methods in the removal of heavy metals from aqueous solutions. Adsorption has many advantages over the other treatment methods since the cost associated with the treatment is very less, removal efficiency is very high and reproducibility of the adsorbents is also possible in the treatment via desorption [7]. Activated carbon is the commercial absorbent that is used to remove heavy metals, but the production cost is high. So recently many types of research have been carried out in producing low-cost adsorbent for the removal of metal ions from aqueous solution. Biosorption is a recent technique where the plant biomass is used as the adsorbents namely rice husk, ground nutshell, coconut shell, sawdust, breadfruit peel, and many other biomasses have been reported.

The present study explored the potential of a freshwater algae *Pithophora cleveana* Wittrock and a *Mimusops elengi* leaf biomass in the removal of zinc metal ions from the aqueous solutions in batch mode of operation. These adsorbents are naturally available and can be produced at a very low cost. The main objective of the present research is to evaluate the biosorption capacity of the zinc metal ion at different operating conditions and to determine the rate-limiting reaction kinetics and isotherm models. This naturally available biomass is very commonly grown in south India in huge quantity and it doesn't have any major application other than acting as a compost. So, the utilization of this waste biomass will give an alternate solution for the removal of pollutants from wastewater.

2. Materials and methods

2.1. Chemicals and adsorbent preparation

Zinc sulfate ($ZnSO_4{\cdot}7H_2O$) of 99.5 purity and other chemicals namely sodium hydroxide (NaOH), hydrochloric acid (HCl), and nitric acid (HNO_3) were supplied by Sigma-Aldrich, India. A stock solution of zinc concentration of 1 g/L was prepared by dissolving 4.442 g of zinc sulfate in 1 L of distilled water. A freshwater algae *P. cleveana* Wittrock that is commonly grown in the tropical region of India and an evergreen tree *M. elengi* that is commonly grown in the Coastal region, Western and Eastern Ghats, Deccan plateau, Gangetic plains, and the Andaman and Nicobar Islands were collected. The collected biomass was washed with deionized water and dried under natural drying for 7 d. Then the biomass was shredded into a particle size of 7.5 mm and kept in a hot air oven at 103°C for 3 h to ensure the complete absence of the moisture content of the biomass. The dried biomass is used for further studies.

2.2. Batch experiments

A known concentration of 100 mL is measured and it is taken in a 250 mL conical flask. To avoid the evaporation and change in solution concentration, stoppers are provided to the conical flask to arrest the evaporation. The batch study is carried out in an orbital shaker with a constant agitation speed at room temperature. After the adsorption, the sample is filtered using Whatman filter paper (42 microns) and the final concentration is measure using atomic adsorption spectroscopy. All the trails were carried out by fixing the influencing parameters as 0.1 g of 75 μm biosorbent in 30 mL of an aqueous solution of initial metal concentration 20 mg/L, at a known pH value of 5 at a constant agitation speed of 180 rpm.

2.3. Isotherm, kinetics, and thermodynamic studies

The interaction of the solute to the adsorbent is influence by metal ion concentration and it is better understood by studying various adsorption isotherms. The present study explored various isotherm models Freundlich, Langmuir, Temkin, Dubinin–Radushkevich (D–R) to find the best fit model with the experimental uptake. To study the equilibrium, contact time concerning various metal ion concentrations a varying zinc metal concentration of 20, 40, 60, 80, and 100 mg/L was used in conjunction with 0.1 g of *M. elengi* and *P. cleveana* Wittrock at a varying contact time of 0.5–300 min. In the present study, pseudo-first and pseudo-second-order rate models, intraparticle diffusion kinetic model, and Elovich's model were employed to analyze the kinetics of biosorption. In addition to isotherm and kinetic study, a thermodynamic study was also explored at a varying temperature between 303 and 333 K to compute Gibbs energy (ΔG), enthalpy of biosorption (ΔH), and entropy of biosorption (ΔS).

2.4. Characterization of adsorbent

Adsorption phenomena can be clearly understood by studying morphology, function groups, and crystalline nature of the biosorbent used in the biosorption process. A scanning electron micrograph (SEM) is used to study the morphological changes occurred on to the surface of the biosorbent before and after the adsorption process. The functional groups present in the biosorbent plays a major role in the uptake capacity of the biosorbent and it is confirmed by Fourier transform infrared spectroscopy (FTIR). X-ray diffraction (XRD) analyzes the crystalline nature of the adsorbent before and after the adsorption process.

3. Result and discussion

3.1. Characterization of adsorbent

Figs. 1 and 2 explore the SEMs of the biosorbent before and after biosorption. From the Figs. 1 and 2, it is clear that the surface changes have occurred during the adsorption process and before adsorption, the surface of the adsorbent is rough and having several pores that will act as the binding site for the metal ion to attached on the surface of the biosorbent. After adsorption, the surface becomes

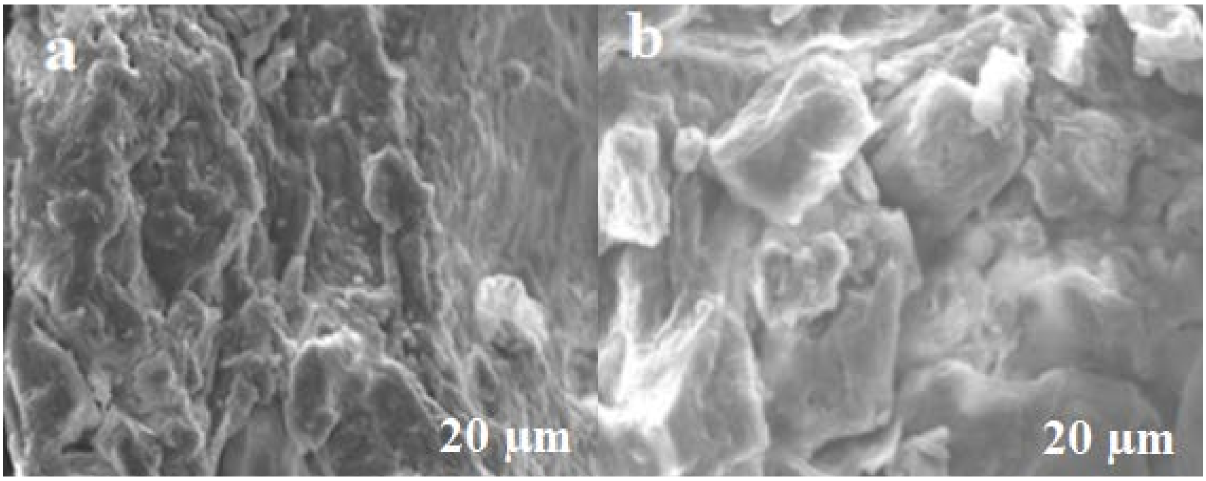

Fig. 1. Scanning electron micrographs of *Pithophora cleveana* Wittrock: (a) before and (b) after biosorption.

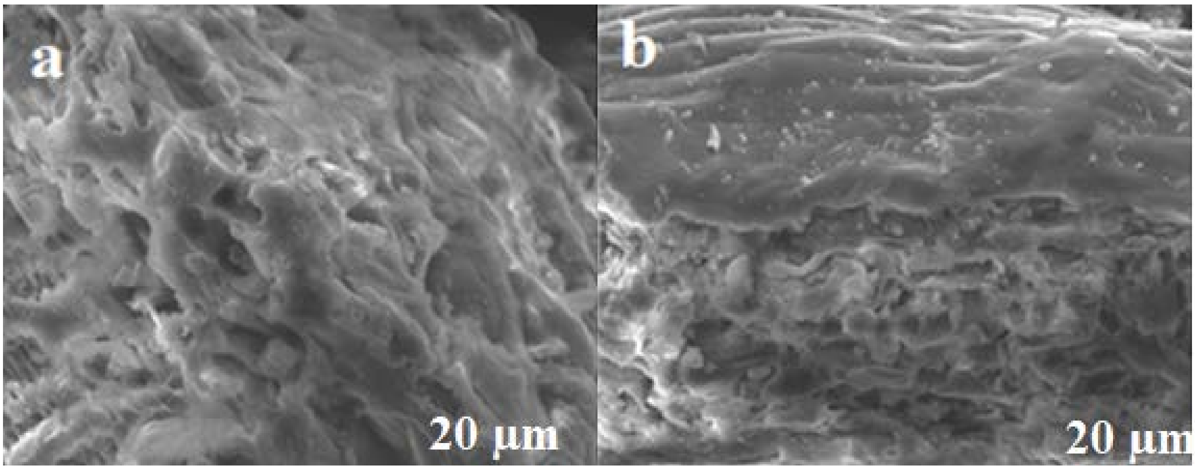

Fig. 2. Scanning electron micrographs of *Mimusops elengi*: (a) before and (b) after biosorption.

smooth and white cloudy precipitation is formed over the surface of the adsorbent and it indicates that the metal ion concentration filled the pores of the adsorbent.

FTIR was analyzed to find the functional groups that are present on the surface of the biosorbent and that will favor the adsorption of zinc metal ion onto the surface. The FTIR results of *P. cleveana* Wittrock showed several peaks and confirmed the presence of different functional groups. For instances, the peak at 3,870 confirmed the presence of alcohol groups (OH, stretch), a peak at 3,150 confirmed the presence of alkane/aromatic/carbonyl acid (C–H, stretch), a peak at 2,850 confirmed the aldehydes group (=C–H, stretch), a peak at 1,500 confirmed aromatic group (C=C, stretch), and a peak at 1,050 confirmed ether groups (C–O, stretch). Similarly, the FTIR results of MC confirmed the presence of several peaks at 3,870; 3,000; 2,390; 1,500; and 1,275 indicated the presence of alcohol (OH, stretch, free), alkane (C–H, stretch), carbonyl acid (OH–stretch), alkene (C=C, stretch), and ether (C–O, stretch) groups. The presence of these functional groups may be enhanced the uptake capacity of the adsorbent.

A spectrum of cellulosic materials is confirmed in XRD pattern with a main and secondary peak at 2θ of 22.4° and 6.29° for *P. cleveana* Wittrock and 24.5° and 14.02° for ME, respectively. These peaks are corresponding to (002) crystallographic panes and (101) organized polysaccharide structure. The planes at (002) and (101) indicate the presence of a native form of cellulose found in a natural source that is cellulose-I polymorphic form. The CI index for raw, zinc loaded *P. cleveana* Wittrock was found to be 48.47%, and 67.9% and raw, zinc loaded *M. elengi* were found to be 41.73% and 62.9%, respectively. These values clearly showed the increase in crystalline material present in the biosorbent after the biosorption of metal ions, which was due to the biosorption of metal ions on the surface of the biosorbent.

3.2. Effect of pH

The pH of a solution is considered as one of the important parameters that influence the adsorption of heavy metals in an aqueous solution [10,11]. The effect of pH in the removal of zinc metal in is studied by varying the pH from 2 to 10 at different concertation varying from 20 to 100 mg/L. Other parameters namely biosorbent dosage of 0.1 g, the particle size of 75 μm, and temperature of 303 K. From Figs. 3a and b, it is clear that the increase in pH from 2 to 5 increased the removal efficiency of the zinc metal ion, whereas a further increase in pH from 5 to 10 decreased removal efficiency. For instance, the removal efficiency increased from 5.72 to 76.43 for pH 2 to 5 and removal efficiency decreased from 76.43% to 7.28% when pH increased from 5 to 10 for *P. cleveana* Wittrock biosorbent. Similarly, for *M. elengi* biosorbent a removal efficiency increased from 6.72% to 73.11% when pH raised from 2 to 5, a further increase in pH from 5 to 10 decreased the removal efficiency from 73.11% to 8.28%. The zinc metal showed a trend of declining sorption when the pH was increased from 5 to 10. This may be considered to the lower polarity of lead and zinc ions at higher pH values. Above the pH value of 5, the biosorption rate was decreased as insoluble metal hydroxides that precipitated were separated before the analysis of the samples. So, from the batch study, pH of 5 is considered as an optimum for further studies.

3.3. Effect of contact time

The influence of contact time in the adsorption process was studied by varying the contact time from 0 to 180 min. Figs. 4a and b explore the adsorption of zinc metal ions at varying concentration. From Fig. 4, it is clear that the removal efficiency of the zinc metal ion is very high during the initial phase of the adsorption process between 0 and 30 min. Further increase in contact time is having only a slight increase in removal efficiency. For instance, at initial concertation of 20 mg/L, when the contact time increased from 0 to 30 min, the removal efficiency increased from 1.53% to 75.5% and 10.52% to 70.39% for *P. cleveana* Wittrock and *M. elengi*. But when the contact time is increased further to 180 min a maximum removal efficiency of 75.9% and 73.11% is achieved for PWC and ME and the difference in removal efficiency is less than 2.15% for a contact time between 30 and 180 min. So, from the batch study, it is concluded that the optimum contact time for the removal of zinc metal ion is 30 min.

3.4. Effect of biosorbent dosage

The mass of the adsorbent is a crucial parameter that decides the economy of the treatment and the removal efficiency of the metal ion. The optimum dose is decided based on the uptake capacity of the adsorbent and removal efficiency of the metal ion. Figs. 5a and b explore the effect of different adsorbent dosage on the removal efficiency of the zinc metal ions. For instance, Fig. 5a explores the effect of adsorbent dosage, increase in adsorbent dosage increased the removal efficiency and decreased the uptake capacity of the biosorbent. This may be at higher dosage the available binding site is excess when compared to the metal concentration and the binding sites are not fully utilized and this results in increased removal efficiency and decreased

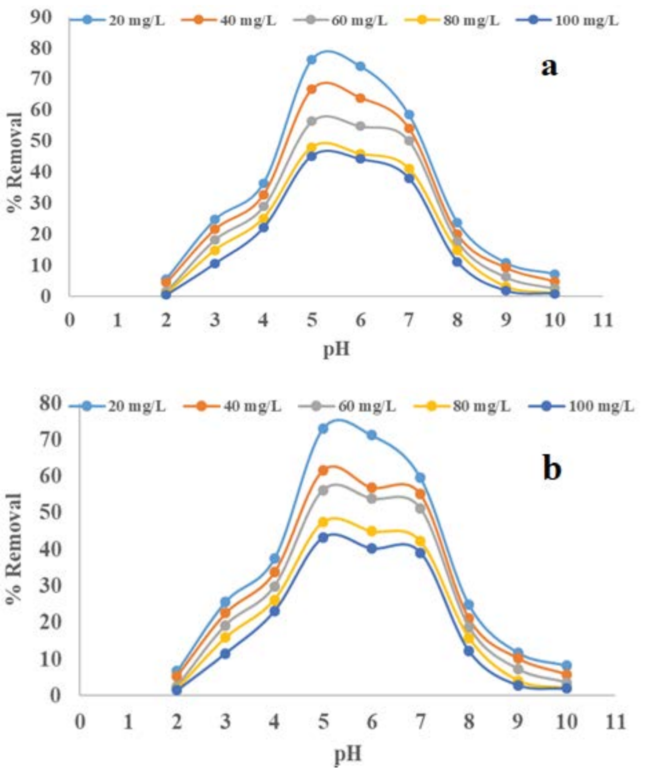

Fig. 3. Effect of pH on biosorption of zinc by: (a) *Pithophora cleveana* Wittrock and (b) *Mimusops elengi*.

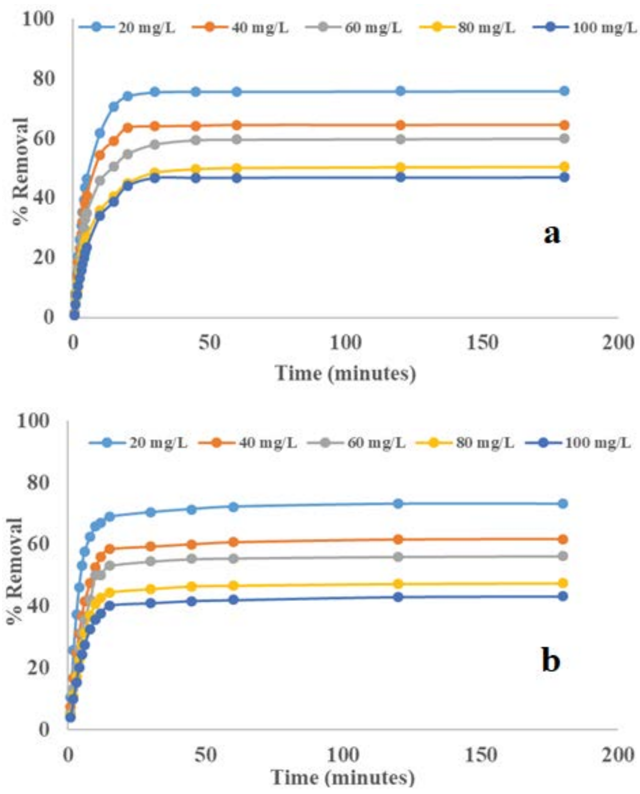

Fig. 4. Effect of contact time on biosorption of zinc by: (a) *Pithophora cleveana* Wittrock and (b) *Mimusops elengi*.

metal uptake [12,13]. For instance, at an initial concentration of 20 mg/L, when biosorbent dosage increased from 0.1 to 0.5 g, removal efficiency also increased from 74.1% to 76.42%, but the difference in removal efficiency is only 2.32%. Whereas the uptake capacity of a biosorbent decreased from 4.446 to 0.917 mg/g for *P. cleveana* Wittrock. Similarly, for *M. elengi* biosorbent a removal efficiency increased from 73.11% to 83.62%, with a decrease in uptake capacity from 4.38 to 0.99 mg/g when biosorbent dosage is increased from 0.1 to 0.5 g. So, from the batch study, it is concluded that biosorbent dosage of 0.1 g is considered as the optimum dosage for the maximum removal efficiency and uptake capacity of the biosorbent.

3.5. Effect of particle size

Figs. 6a and b show the removal efficiency of the zinc metal ion using *P. cleveana* Wittrock and *M. elengi*. From the results, it is clear, an increase in particle size decreased the removal efficacy of the metal ion. This may be due to an increase in particle size will result in reduced surface area and this will reduce the binding capacity of the metal ion to the surface. Whereas a decrease in particle size will increase the surface area and also increase the binding sites that favor the adsorption at a higher rate. For instance, when particle size is increased from 75 to 212 μm, the removal efficiency decreased from 74.1% to 58.5% and 73.11% to 54.28% for *P. cleveana* Wittrock and *M. elengi*. So, a particle size of 75 μm is considered as the optimum particle size for the maximum biosorption of zinc metal ion.

3.6. Effect of temperature

Temperature plays a very important role in the adsorption of the heavy metal's ion onto the adsorbent. The adsorbate–absorbent interaction can be clearly understood by studying the impact of temperature on the removal mechanism of heavy metals. Figs. 7a and b explore the removal efficiency of *P. cleveana* Wittrock and *M. elengi* at different temperatures. From the results, it is clear that an increase in temperature decreased the removal efficiency. For instance, at an initial concentration of 20 mg/L, when a temperature is increased from 303 to 333 K, the removal efficiency was decreased from 74.1% to 60.3% and 73.11% to 57.28% for *P. cleveana* Wittrock and *M. elengi*, respectively. From the batch study, it is concluded, that a temperature of 303 K is considered as the optimum temperature for the maximum removal of zinc.

3.7. Adsorption isotherm

The removal of solute in a solution is due to the solid–liquid interaction and results in the accumulation of solute in the adsorbent surface. The initial concentration of the solute decided the number of metal ions attached to the surface and adsorbent and it is very important to study the effect of initial metal concentration to understand the adsorption mechanism [14]. Since the adsorption process is complex, four different isotherms were studied to understand the complexity of the adsorption process. Langmuir isotherm model is valid for the single monolayer's adsorption and

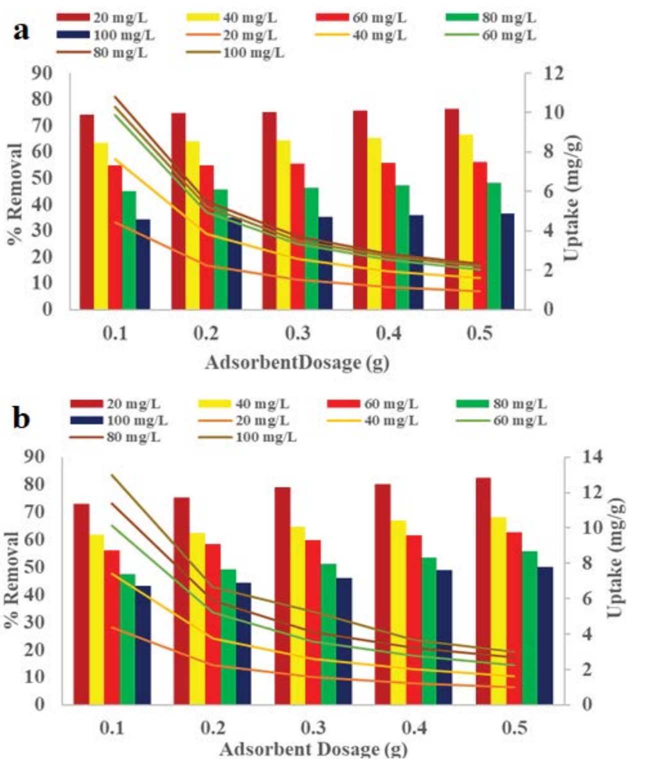

Fig. 5. Effect of biosorbent dosage on biosorption of zinc by: (a) *Pithophora cleveana* Wittrock and (b) *Mimusops elengi*.

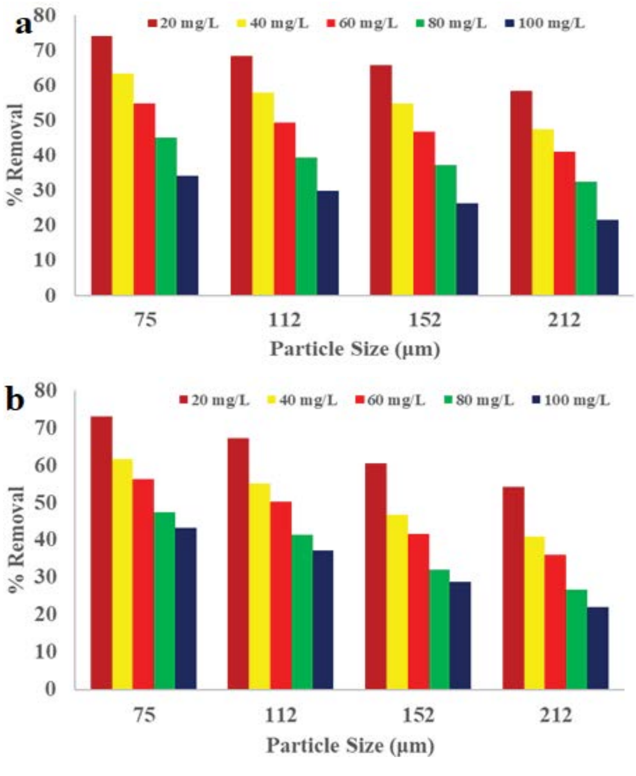

Fig. 6. Effect of biosorbent size on biosorption of zinc by: (a) *Pithophora cleveana* Wittrock and (b) *Mimusops elengi*.

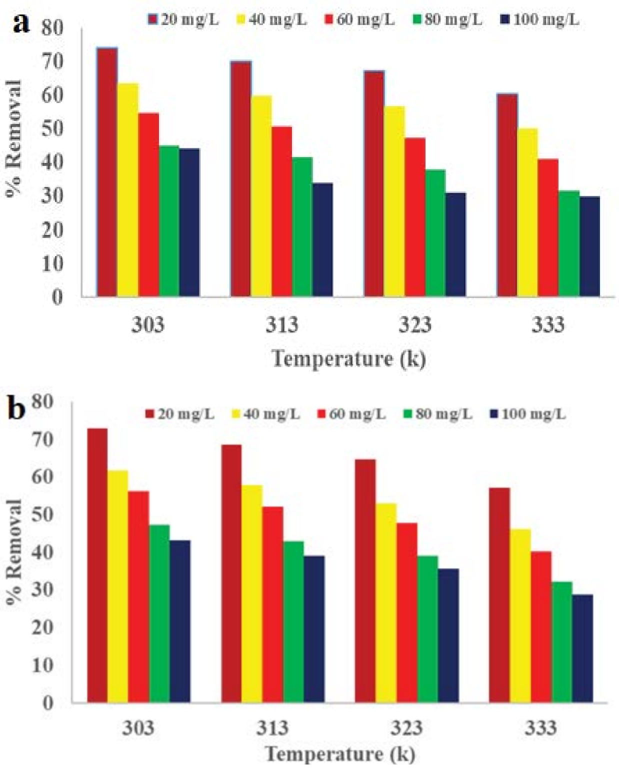

Fig. 7. Effect of temperature on biosorption of zinc by: (a) *Pithophora cleveana* Wittrock and (b) *Mimusops elengi*.

a correlation coefficient of 0.996 and 0.992 is obtained for *P. cleveana* Wittrock and *M. elengi* biosorbent. The separation factor R_L was calculated using the equation $R_L = (1/1 + b_L C_0)$, where b_L represents the rate constant of the Langmuir model (L/mg) and C_0 represents the highest initial concentration (mg/L). The R_L values show that adsorption is irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), linear ($R_L = 0$), and unfavorable ($R_L > 1$). The R_L values were calculated as 0.071 and 0.142 for adsorption of zinc using *P. cleveana* Wittrock and *M. elengi*. From the results, it was clear that the values were between 0 and 1 and it represents the favorability of adsorption [15,16]. Freundlich isotherm predicted the uptake capacity of the biosorbent to a correlation coefficient of 0.924 and 0.989 for *P. cleveana* Wittrock and *M. elengi*. A three-parameter model Temkin and D–R isotherm model is studied. The correlation coefficient of Temkin isotherm was found to be 0.951 and 0.989 for *P. cleveana* Wittrock and *M. elengi*. Whereas, the correlation coefficient of the D–R isotherm model is found to be 0.948 and 0.859. The values of E (kJ/mol) for *P. cleveana* Wittrock and *M. elengi* obtained by the D–R isotherm model was found to be 7.11 and 20.16 kJ/mol, respectively. The adsorption may be physic-sorption or chemic-sorption based on the value of E (kJ/mol). If $1 < E$ (kJ/mol) < 8, the physic-sorption becomes a dominant mechanism, and if $8 < E$ (kJ/mol) < 16, the sorption reaction can be explained by a chemic-sorption mechanism. So, from the results, it was concluded adsorption of zinc by *P. cleveana* Wittrock was physic sorption and *M. elengi* was chemic sorption [17]. From the adsorption isotherm study, it was concluded that the predicted uptake

Table 1
Equilibrium constants for zinc onto *Pithophora cleveana* Wittrock and *Mimusops elengi*

Isotherm	Constants	*Pithophora cleveana* Wittrock	*Mimusops elengi*
Langmuir	Q_{max} (mg/g)	11.9	16.393
	b (L/mg)	0.129	0.0601
	R_L	0.071	0.142
	R^2	0.9961	0.992
Freundlich	K_f (mg/g)	1.532	1.5872
	n (g/L)	0.359	2.165
	R^2	0.9249	0.989
Temkin	A_T (L/mg)	1.265	0.581
	b_T	987.94	694.016
	R^2	0.9518	0.989
D–R	K_d (mol^2 kJ^2)	0.00988	0.00123
	Q_0 (mg/g)	9.86	10.88
	R^2	0.9484	0.8598
	E (kJ/mol)	7.11	20.16

of the absorbent was in the order of Langmuir > Temkin > D–R > Freundlich for *P. cleveana* Wittrock and of Langmuir > Freundlich > Temkin > D–R > for *M. elengi*. Adsorption isotherm study concluded that the adsorption process is based on single monolayer adsorption. Table 1 demonstrates the different parameters of four different isotherm models.

3.8. Adsorption kinetic study

Kinetics of solute uptake information is required for selecting optimum operating conditions for full-scale batch process. The kinetic study was studied by varying initial metal ion concentration and observed at different time intervals. For the kinetic study, it is concluded that the adsorption was maximum initially for 30 min and a further increase in contact time doesn't have much impact on the removal efficiency of the zinc metal ion. This fast adsorption at the initial time is due to the surplus binding site [18]. Four different kinetic models were developed to understand the adsorption process involved in the zinc removal mechanism. Table 2 demonstrates the constants of different kinetic models. Based on the regression coefficient, it is concluded that pseudo-first-order kinetics is found to be the best fit model for *P. cleveana* Wittrock biosorbent and pseudo-second-order kinetic model is found to be the best fit model for the *M. elengi* biosorbent. The coefficient of regression was in the order of pseudo-first-order kinetic model > Elovich kinetic > intraparticle diffusion kinetic model > pseudo-second-order kinetic model for *P. cleveana* Wittrock and pseudo-second-order kinetic model > Elovich kinetic > pseudo-second-order kinetic model > intraparticle diffusion kinetic model for *M. elengi*.

3.9. Thermodynamic study

Table 3 demonstrates the thermodynamic paraments at different temperatures. The negative values of $\Delta G°$

Table 2
Constants of different kinetic models of zinc on to *Pithophora cleveana* Wittrock and *Mimusops elengi*

Initial concentration (mg/L)	*Pithophora cleveana* Wittrock			*Mimusops elengi*		
Pseudo-first-order kinetic model						
	k_1 (1/min)	q_{eq} (mg/g)	R^2	k_1 (1/min)	q_{eq} (mg/g)	R^2
20	0.204	4.522	0.995	0.064	4.38	0.810
40	0.186	7.80	0.991	0.049	7.4	0.8585
60	0.175	10.16	0.989	0.047	10.12	0.790
80	0.159	11.27	0.991	0.044	11.38	0.799
100	0.145	12.50	0.997	0.043	12.96	0.837
Pseudo-second-order kinetic model						
Initial concentration (mg/L)	k_2 (g/mg min)	q_{eq} (mg/g)	R^2	k_2 (g/mg min)	q_{eq} (mg/g)	R^2
20	0.34	4.59	0.628	0.89	4.39	0.9993
40	0.15	0.95	0.255	1.1	7.5	0.9965
60	0.1	10.37	0.204	0.81	10.13	0.998
80	0.095	11.31	0.2	0.72	11.39	0.9982
100	0.059	14.04	0.097	0.63	12.98	0.9982
Intra-particle diffusion kinetic model						
Initial concentration (mg/L)	K_p	C	R^2	K_p	C	R^2
20	1.3028	–0.4082	0.8665	0.2074	2.472	0.4375
40	2.1993	–0.543	0.8552	0.4173	3.5055	0.5068
60	2.8313	–0.7143	0.8652	0.602	4.517	0.5072
80	3.1102	–1.0451	0.8879	0.6656	5.1679	0.5035
100	3.837	–1.8299	0.9079	0.7749	5.6346	0.5302
Elovich kinetic model						
Initial concentration (mg/L)	γ	α	R^2	γ	α	R^2
20	0.765	2	0.9814	1.518	9.77	0.7442
40	0.45	3.59	0.9829	0.78	7.2	0.8054
60	0.351	4.61	0.9853	0.541	7.8	0.8032
80	0.324	4.71	0.9831	0.489	9.339	0.8012
100	0.267	5.098	0.9704	0.425	9.609	0.8229

affirm the possibility of the process and the spontaneous nature of biosorption with a high inclination of zinc onto the *P. cleveana* Wittrock and *M. elengi* at lower temperatures. However, the entropic contribution is even larger than the free energy of biosorption $\left(\Delta G^\circ = \Delta H^\circ - T\Delta S \angle 0\right)$. Hence, it can be concluded that the biosorption of zinc is entropic. The standard enthalpy changes ΔH° was calculated as –17.30 and –4.5 kJ/mol for *P. cleveana* Wittrock and *M. elengi* while the standard entropy changes ΔS° was determined as 0.181 and 0.053 kJ/mol K for *P. cleveana* Wittrock and *M. elengi*. The values of ΔH° is negative, representing an exothermic reaction for the biosorption reaction. The value of ΔS° can be used to indicate whether the sorption reaction is ascribed to an associative or dissociative mechanism. If ΔS° becomes greater than 10 J/mol/K, the dissociative mechanism becomes dominant [19]. From the result, the positive value of entropy changes ΔS° indicated the free metal ion ratio to the ions interacting with nanofiber adsorbents will be greater than the adsorbed state and also increase in randomness at the solid/solution interface during the biosorption and the significant change in entropy implied irreversibility of the process and it is a dissociative mechanism. Similar results were observed for zinc biosorption

Table 3
Thermodynamic constants for the biosorption of zinc ions at different temperatures

Adsorbent	Temperature (K)	K_a (L/mg)	$-\Delta G^\circ$ (kJ/mol)	$T\Delta S^\circ$ (kJ/mol)
Pithophora cleveana Wittrock	303	0.1288	22.80	5.50
	313	0.0995	22.98	5.68
	323	0.0982	23.16	5.86
	333	0.0648	23.34	6.04
Mimusops elengi	303	0.0601	20.84	16.34
	313	0.0570	21.38	16.88
	323	0.0522	21.92	17.42
	333	0.0518	22.46	17.96

Table 4
Comparison of the zinc biosorption capacity of the present study with those reported in the literature

S. No	Adsorbent	Zn	Reference
1	Groundnut shell	9.57	[22]
2	*Pinus pinaster* bark (pine tree)	1.18	[23]
3	Orange peel	5.25	[24]
4	Banana peel	5.8	
5	Peanut husk	0.48	[25]
6	Pecan shell	13.90	[26]
7	Coconut shells carbon	0.39	[27]
8	Apricot stones carbon	0.41	
9	Peanut hulls	9	[28]
10	Jute fibers	5.95	[29]
11	Cabbage waste	7.89	[30]
12	Coffee residues binding with clay	13.4	[31]
13	Olive mill solid residue	5.4	[32]
14	Sesame straw biochar	34	[33]
15	Peat moss	13.27	[34]
16	Purolite active carbon	12.9	[35]
17	*Sargassum* sp.	1.51	[36]
18	*Ulva* sp.	7.96	[37]
19	*Codium vermilara*	14.7	[38]
20	*Asparagopsis armata*	4.6	
21	*Chondrus crispus*	4.8	
22	*Fucus spiralis*	10.9	
23	*Ascophyllum nodosum*	1.4	
24	*Pithophora cleveana* Wittrock	13.58	Present study
25	*Mimusops elengi*	12.96	Present study

onto *Bacillus drentensis* and cells of *Candida utilis* and *Candida tropicalis*, respectively [20,21]. Table 4 compares the uptake capacity of the present study with the previous research.

4. Conclusion

The following conclusion arrived for the current investigation:

- The maximum removal efficiency of 74.11% and 73.11% is obtained for *P. cleveana* Wittrock and *M. elengi* at optimum conditions of contact time of 30 min, pH of 5, biosorbent dosage of 0.1 g, biosorbent pawrticle size of 75 m, initial metal ion concentration of 20 mg/L, and temperature of 303 K.
- Maximum uptake of 13.58 and 12.96 mg/g was achieved at an initial concentration of 100 mg/L for *P. cleveana* Wittrock and *M. elengi*.
- Langmuir adsorption isotherm model is found to best fit for the experimental uptake with a maximum regression coefficient of 0.996 and 0.992 for *P. cleveana* Wittrock and *M. elengi*.
- Kinetic study reviled that, a pseudo-first-order kinetic model was found to be the best fit for *P. cleveana* Wittrock biosorbent and pseudo-second-order kinetic model was found to be the best fit for *M. elengi* absorbent.
- The thermodynamic study concludes that the reactions are exothermic and spontaneous.

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