Cadmium removal using potato peels as adsorbent: kinetic studies

Basak Berna Palabıyık[a], Huseyin Selcuk[b], Yalcin Askin Oktem[c,*]

Engineering Faculty, Environmental Engineering Department, Istanbul University, Cerrahpasa, Avcilar, Istanbul, Turkey,
Tel. +905344873776; email: oktemy@istanbul.edu.tr (Y.A. Oktem), Tel. +905358480310; email: basakbernaa@gmail.com (B.B. Palabıyık),
Tel. +905325525627; email: hselcuk@istanbul.edu.tr (H. Selcuk)

ABSTRACT

In this study, untreated waste potato peels were used as adsorbents for treatment and cadmium removal mechanisms were investigated. Maximum removal efficiency was 76% at an initial concentration of 100 mg L^{-1} of Cd(II) at pH 5.8 in an aqueous solutions at room temperature; 7.61 mg of cadmium was removed per gram of adsorbent. However, as the initial concentration increased, the removal efficiency decreased. Under optimum conditions, two parameters equilibrium isotherms (Langmuir, Freundlich, Temkin etc.) were applied. The Freundlich isotherm has the highest correlation (99.9%) in isotherms. Isothermal adsorption capacity (K_F) has 19.94 mg g^{-1} and heterogeneity factor ($1/n$) 1.0 were determined. In adsorption, it was found that both the boundary layer diffusion and the intra-particle diffusion steps were effective, and the determination of the adsorption rate showed that the Type I pseudo-second-order equation had a high correlation (99%) at all concentrations.

Keywords: Adsorption; Cadmium; Potato peels; Kinetics; Isotherms

1. Introduction

Many sources of pollution, such as industrialisation, transportation and uncontrolled waste storage, lead to the accumulation of heavy metals in plants, animals and human beings [1,2]. Cadmium (Cd), which is one of the heavy metals, can be found in the structure of soil, water and sediment, as well as in industrial activities such as the production of phosphorus fertilisers, other sources as sewage wastes or atmospheric transport [3]. According to the World Health Organization, Cd uptake of 25 μg kg^{-1} of body weight in food and 3 μg L^{-1} of drinking water is acceptable [4]. When humans are exposed to high Cd levels, kidney, lung, and prostate cancers have been observed [5]. Researchers reported other effects, such as bone erosion, anaemia, tooth decay and loss of sense of smell also. Different methods have been proposed for the removal and recovery of metal ions (including Cd) from water and wastewater. The mentioned methods include evaporation, electro-deposition, ion exchange, precipitation, flocculation, sorption, activated carbon adsorption, solvent extraction, reverse osmosis, electrodialysis and membrane separation [6,7]. Some of these methods are as follows: precipitation by sodium diisobutyldithiophosphinate [8], multi-stage acid and alkali solution process [9] and lime and magnesium [10]. In order to precipitation; cementation, researchers have reported that Cd can be removed using a bivalent metal [11]. In a different study of cementation, Younesi et al. [12] studied removing cadmium at different concentrations, in the range of pH 5.2–5.4, using zinc dust. Another technique of removing is the membrane separation. Liquid membranes [13], hollow-fibre-supported liquid membranes [14], supported liquid membranes [15] and emulsion liquid membranes [16] can be used to remove Cd from aqueous solutions. Ion exchange operations are essentially chemical reactions between an electrolyte in solution and an insoluble electrolyte with which the solution is contacted. Many researchers have studied to elimination various metals in aqueous solutions using an ion exchanger.

* Corresponding author.

Na-Y zeolites [17], amberlite IRC718 [18], acidic-solution based on an ion exchange resins [19], and amberlite IR120 [20] have been used for ion exchanges. Solvent extraction is used mainly for recovering or separating metal ions from aqueous solutions having higher concentrations. In some research, with liquid–liquid extraction using specific extractants from solutions has been recovered cadmium, cobalt and nickel. These studies reported the use of different solvents, such as Cyanex 272 [21] and Cyanex 923 [22]. There are also synthetic, naturally occurring and waste oxidic materials used as adsorbents. As an example, thiol-functionalised mesoporous silica [23], waste $Fe(III)/Cr(III)$ hydroxide [24], phosphogypsum which is a by-product of the phosphate fertiliser industry [25] calcite and hydroxyapatite [26] have been used. However, these methods that aforementioned have certain disadvantages, such as operational costs, chemical requirement, high energy consumption and waste sludge disposal [27]. The adsorption process is an appropriate treatment method, compared with other methods, in terms of easiness and efficacy in wastewater treatment [28,29]. In wastewater treatment systems using an adsorption process, the regeneration of the adsorbent and/or disposal of the adsorbate-loaded adsorbent (or spent adsorbent) are the important problems [30]. However, nowadays are being obtained from post-adsorption products (i) fertilisers, (ii) catalysers, (iii) carbonaceous metal nanoparticles, (iv) feed additives and (v) biologically active compounds [31].

Adsorption is a mass transfer process that involves the accumulation of substances at the interface of two phases, such as a liquid–liquid, gas–liquid, gas–solid or liquid–solid interfaces. If the interaction between a solid surface and the adsorbed molecules has a physically, the process is called physiosorption. In this instance, the attraction interactions are van der Waals forces and, as they are weak, the results are reversible. On the other hand, if the attraction between adsorbed molecules and the solid surface is due to chemical bonding, the adsorption process is called chemisorption. By means of the adsorption process, a treatment process with low cost and lower environmental risks other than treatment methods can be realised. Commonly used active carbon and ion exchange resins are relatively expensive according to other adsorbents, so a large number of studies on the removal of various metals using low-cost adsorbents have been reported. In these studies, many materials, such as waste sludge [32], potato peels [33], olive kernels [34], nanoparticles [35], *Laminaria japonica* [36], brown-red-green algae [37], *Aspergillus niger* [38], *Neurospora crassa* [39], *Mucor hiemalis* [40], *Botrytis cinerea* [41], waste algae [42] and surface-modified bacteria [43] were used as adsorbents. There has also been a large amount of research on low-cost alternatives for Cd removal [44]. Cadmium studies with low-cost adsorbents whose chemical modifications have been developed are as follows: agava baggase with HCl-acid modified with 1 g L^{-1} adsorbent at 12.50 mg g^{-1} pH 5, modified with HNO$_3$ under the same conditions 13.50 mg g^{-1}, with NaOH modification 18.32 mg g^{-1}, untreated agava baggase 13.27 mg g^{-1} result was obtained [45]. In another study using a banana peel as the adsorbent, 5.71 mg of Cd were removed at pH 3 using 30 g L^{-1} of adsorbent [46]. In an adsorption study using KCl-modified orange peel, 5 g L^{-1} of adsorbent using and 125.53 mg Cd g^{-1} removal in pH 5–5.5

were observed [47]. Using 1 g L^{-1} of adsorbent with modified *Cucumis sativus* peels at pH 5, 58.14 mg Cd g^{-1} were removed from aqueous solutions. In the same study, untreated (raw) rice straw was used as an adsorbent and at pH 2.6 a slightly different value of 13.84 mg g^{-1} was obtained [48].

The waste potato peels used in this study is low-cost, compared to other adsorbents, and its surface area is quite low, compared to other adsorbents, because it is not activated by any chemical pre-treatment. The use of this form of adsorbent which has low surface area, is not common. The characteristics (isotherm and kinetic expressions) of the adsorbent, which was not treated, are important for understanding of usability. In this study, potato peels, which is food waste were used as a low-cost adsorbent, and cadmium removal efficiency and adsorption characteristics were investigated.

2. Materials and methods

2.1. Adsorbent preparation

Potato peels were collected from the waste of a local restaurant. The materials were washed thoroughly, to remove the soil on the peels' surface, and then rinsed again with distilled water. A lab oven was kept at 40°C–70°C was used until the water content in the peels was completely eliminated. To increase surface area, a commercial mill which has smashed the dried material was used. The average particle size of the material was between 10–50 μm and the weighted mean was determined to be 16.08 μm. No treatment was performed to increase the surface area of the adsorbent and the specific surface area was determined to be 3 m^2 g^{-1}, which was a very low surface area according to commercial adsorbent. The surface area of commercially activated carbon is 400–1,000 m^2 g^{-1}; this value is sometimes exceeded in special products [49].

2.2. Experimental procedure and methods

In this study, for cadmium solutions analytical-grade Cd salt (Sigma-Aldrich Co., St. Louis, Missouri, USA, $Cd(NO_3)_2 \cdot 4H_2O$) was used. The residual heavy metal concentration in the solution was measured using a Perkin Elmer (Waltham, Massachusetts, USA) (Aanalyst 400) brand atomic adsorption spectrometer. In the spectrometer, C_2H_2 and dry air, as well as combustible phase-support gases, were used and measurements were taken at a 228 nm wavelength. The analysis was repeated three times for each sample, and the results were statistically interpreted. During the preparation and characterisation of the material, all drying and burning processes were carried out in a calibrated oven (Willi-Memmert-Straße 90, 91186 Büchenbach, German) - muffle furnace (Carbolite Gero Limited, Parsons Lane, Hope, Hope Valley, S33 6RB, UK).

2.3. Adsorption studies

Adsorption capacity experiments were carried out in a 100 ml Erlenmeyer flask containing 50 ml of Cd solution (10–200 mg L^{-1}). Used adsorbent (0.05–10 g), a pH of 2–12 and mixing times of 15–2,880 min^{-1} was predetermined. Sodium hydroxide (NaOH) and nitric acid (HNO$_3$) were used to

adjust the pH of the metal solutions. The batch experiments were carried out with a heated, multi-chamber mixer at a rotation speed of approximately 100 rpm and a temperature of 20°C–50°C. Following the process, the adsorbent was centrifuged to separate it from the liquid phase. Residue measurements were taken from the upper phase by centrifugation for 10 min at a rotation speed of 11,000 rpm [50].

2.4. Data analysis

The equilibrium sorption data were fitted into Langmuir, Freundlich, Temkin and Dubinin–Radushkevich (DRK) isotherms. In the data analysis, the least squares method was applied. At the results, the analysis was shown that the isotherm and kinetic models with the highest correlation. Amount of the cadmium adsorbed by the potato peels was calculated using the equation given below.
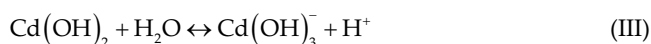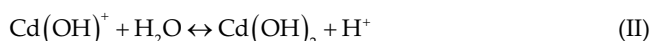
$$q_t = \frac{C_0 - C_e}{m} \times V \tag{1}$$

Here q_t is the amount of metal ions adsorbed per unit weight of adsorbent (mg g^{-1}), C_i is the initial cadmium concentration (mg L^{-1}), C_e is the equilibrium concentration (mg L^{-1}), m is the adsorbent weight used in the experiment (g) and V is the volume of solution used in the experiment (ml). The removal percentage ($R\%$) of cadmium was calculated for each run by the following expression:

$$R(\%) = \left[\frac{C_i - C_e}{C_i}\right] \times 100 \tag{2}$$

2.5. pH

The initial metal concentration was 100 mg Cd(II) L^{-1} and 10 g of potato peel powder was used as an adsorbent. The adsorption was carried out about 100 rpm for 4 h at room temperature. The initial pH of the solution is very important for many studies with heavy metals and various pollutants [51,52]. Therefore, between initial values of pH (2–9) were studied. Cadmium removal gradually increased between pH 2–5.8, but it was decreased after pH 5.8. At this pH, it is known that forms cadmium hydroxide complexes and it is precipitated [53–55]. As a result, pH 5.8 was determined as the pH value to be used at the start of the study. Species distribution of Cd(II) in pure water as function of pH at 25°C, following equations are also given.

$$Cd^{2+} + H_2O \leftrightarrow Cd(OH)^+ + H^+ \tag{I}$$

$$Cd(OH)^+ + H_2O \leftrightarrow Cd(OH)_2 + H^+ \tag{II}$$

$$Cd(OH)_2 + H_2O \leftrightarrow Cd(OH)_3^- + H^+ \tag{III}$$

The solution below pH 6, cadmium is ion. At the more alkaline range, precipitation plays a main role in removing the Cd(II) ions as Cd(OH)$_2$(S) [30].

2.6. Amount of adsorbent

The amount of adsorbent used to determine both the effective adsorption and the amount to be used economically too. For this purpose, optimum amount of adsorbent was found by testing different absorbent amounts at 100 mg Cd(II) L^{-1} for 4 h at pH 5.8. The amount of adsorbent was used between 0.1–10 g and since there was no significant difference in adsorption in this range, 1 g, which is the lowest amount, was taken.

2.7. Contact time

To determine the effect of contact time on Cd(II) adsorption, the pH was adjusted to 5.8 in solutions with an initial concentration C_0: 100 mg L^{-1}, with 1 g of potato peels. In the first 10 min, adsorption increased rapidly. After the first 20 min, the adsorption rate was dropped. Equilibrium conditions occurred in approximately 1 h. The contact time was taken as 90 min for most of the adsorption to be completed.

2.8. Initial concentration of adsorbate

To determine the effect of beginning adsorbate concentrations, a pH of 5.8, 1 g of adsorbent and a duration of 90 min were used. The highest cadmium removal efficiency per adsorbent was 7.61 mg g^{-1} (76%) at 100 mg L^{-1} initial concentration (Fig. 1).

2.9. Effect of temperature

Experiments were also performed at different temperatures (20°C, 30°C, 40°C and 500°C). The cadmium removal at all temperatures did not change much depending on the temperature (Fig. 2).

3. Results and discussion

3.1. Investigation of cadmium removal mechanism

3.2. Diffusion-based kinetic models

In order to find the mechanism that is potent on adsorption, various models can be used with the aim of determining
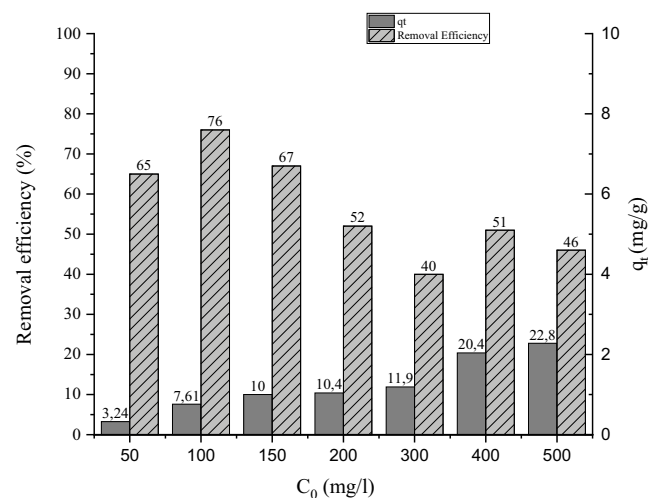

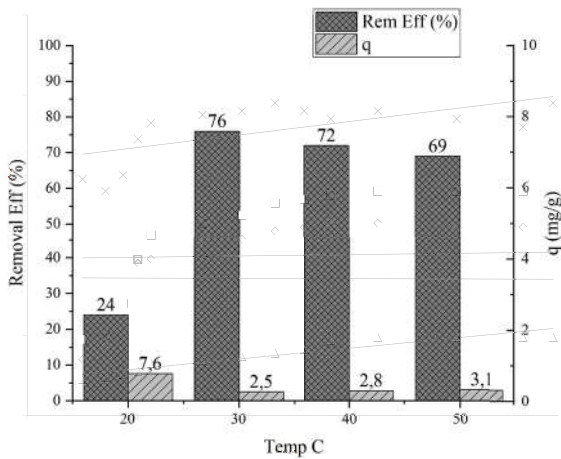Fig. 1. Effect of initial cadmium concentration.

Fig. 2. Cadmium removal and adsorption capacity according to temperature.

the rate limiting step, such as boundary-layer diffusion and intra-particle diffusion. The cadmium in the liquid phase is neglected as it is transported towards the boundary of the liquid film layer surrounding adsorbent, since good mixing in system.

3.3. Boundary layer diffusion

The next step consists of the diffusion of the solute from the liquid film to the solid surface (boundary layer diffusion). In the boundary layer diffusion model, it is assumed that the substance concentration (C_t) at the beginning is at a very low level and intra-particle diffusion is negligible. The time-varying covariate of the concentration depends on the liquid–solid transfer coefficient β_L, as follows:

$$\frac{dC}{dt} = -\beta_L S (C - C_t) \tag{3}$$

Here β_L (cm min^{-1}) is the external mass transfer coefficient, C_t (mg L^{-1}) is the substance concentration at any time, C (mg L^{-1}) is the initial substance concentration and S is the specific surface area for mass transfer. The external mass transfer coefficient is calculated from the slope of the C_t/C_0 curve plotted against time. As the external mass transfer coefficient moves higher, external mass transfer resistance moves lower [56,57].

3.4. Intra-particle diffusion

In the third step, diffusion of the solute into the particle occurs (intra-particle diffusion). It is possible to see the intra-particle diffusion as a rate limiting step. The model can be expressed using the equation defined by Weber and Morris [58].

$$q_t = k_p t^{1/2} \tag{4}$$

where q_t is the amount of adsorbed material per unit mass of adsorbent at time t (mg g^{-1}), and k_p is the intra-particle diffusion coefficient (mg g^{-1} min$^{-0.5}$).

3.5. Reaction-based kinetic models

Kinetic evaluation of Cd(II) adsorption, Lagergren's pseudo-first-order and pseudo-second-order reaction rate equations (types 1–5) were made. Lagergren's pseudo-first-order rate equation is given below:

$$\frac{dq_t}{dt} = k_L (q_e - q_t) \tag{5}$$

where q_e is the amount of adsorbed Cd(II) in equilibrium (mg g^{-1}), q_t is the amount of Cd^{2+} adsorbed at time t (mg g^{-1}), k_L is the speed constant for the pseudo-first-order (min^{-1}). Under certain boundary conditions, $t = 0$, and $(q_e - q_t) = 0$ becomes the following equation:

$$\log(q_e - q_t) = \log q_e - \frac{k_L}{2.303} t \tag{6}$$

The values of $\log(q_e - q_t)$ were linearly correlated with t. The plot of $\log(q_e - q_t)$ vs. t should give a linear relationship (Lagergren plot) in which k_1 and q_e can be determined from the slope and intercept of the plot, respectively. The general expression of the Elovich model is given below:

$$\frac{dq_t}{dt} = \alpha \exp(\beta q_t) \tag{7}$$

where q_t is the amount of Cd^{2+} adsorbed at time t (mg g^{-1}), α is the initial Cd(II) sorption rate (mg g^{-1} min^{-1}), and β is the desorption constant (g mg^{-1}). If the equation is rearranged, it takes on a linear form, as shown below:

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \tag{8}$$

The kinetic data has also been studied using a further analysis method, a type-1 pseudo-second-order rate equation:

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \tag{9}$$

Here, k_2 is the pseudo-second-order adsorption rate constant (g mg^{-1} min^{-1}), q_e is the amount of Cd(II) adsorbed at equilibrium (mg g^{-1}), q_t is the amount of Cd(II) adsorbed at time t (mg g^{-1}). For the boundary conditions $t = 0$ to $t = 1$ and $q_t = 0$ to $q_t = q_t$, the integrated form of the equation is obtained, and, consequently, the linear form given below is obtained.

$$\frac{t}{q_t} = \frac{t}{k_2 q_e^2} + \frac{1}{q_e} t \tag{10}$$

3.6. Adsorption kinetics

In the first step the removal of dissolved matter, the dissolved material is transported towards the liquid film layer surrounding the adsorbent bulk solution transport. This process is neglected, as the mixture is sufficient [59,60]. The second step is the diffusion of the solute from the liquid film to the solid surface (film mass transfer/boundary

layer diffusion). At the kinetic studies beginning; pH = 5.8, at 100 ml volume, different of cadmium concentrations were studied out with 1 g of adsorbent and 90 min of contact time. The pH was approximately held at 6, to prevent the formation of hydroxyl deposits of cadmium. Therefore, from this pH range in the study is cadmium ionic state. It has been stated by many researchers that the steps was completely affected by the adsorption rate are the boundary layer and intra-particle diffusion [61]. The effect of intra-particle diffusion on the adsorption process can be found by plotting the q_t value vs. the square root of the time (Eq. (4)) [62]. The slope will give the rate constant. Correlation coefficients of the curves in the intra-particle diffusion model developed for this purpose vary between 0.41–0.87 (Fig. 3).

The intra-particle diffusion rate constant (k_p) was calculated from the slope of the curves; its value was found to be 0.0534 mg g^{-1} min$^{-0.5}$. Because of this low correlation, it can be said that boundary layer diffusion does not affect the adsorption rate. When the diffusion model curve pass from origin of coordinate system shows that there is no boundary layer effect. As a result, we can conclude that intra-particle diffusion is not the step that controls the rate. When analysing the kinetics of an adsorption system, the suitability of the data to the rate models of the data should be considered [63,64]. In this study, pseudo-first and pseudo-second-order rate (types 1–5) kinetic models were applied. Kinetic expressions and graphs with the highest correlation are included. Rate parameters and correlation constants are given in Table 1 at different initial cadmium concentrations. At the different cadmium concentrations,
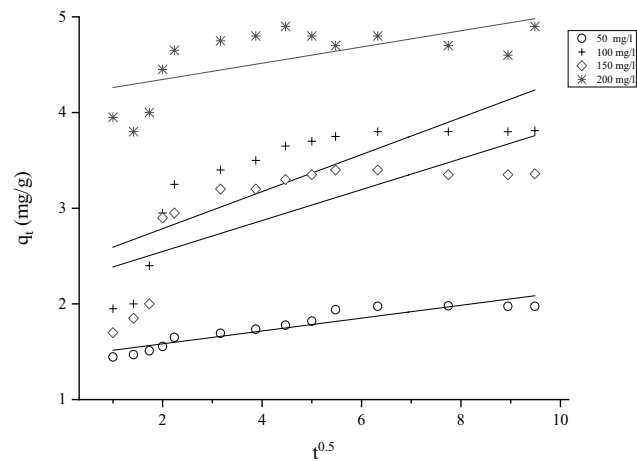
Type-I pseudo-second-order rate equations have a very high correlation coefficient (99%) (Fig. 4). Types II–V rate equations' graphs have low correlation coefficients, so that's why it is not shown in this study, but the experimental data for the two models have the highest correlation used in the study are shown in Fig. 5.

3.7. Isotherm models

Two fundamental models, the Langmuir isotherm (11) and the Freundlich isotherm (12), have been used to assess
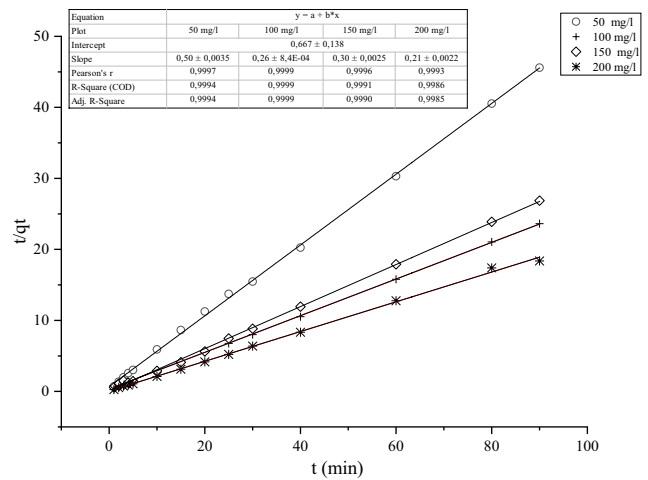
Fig. 4. Rate curves and experimental data.

Fig. 3. Intra-particle diffusion.
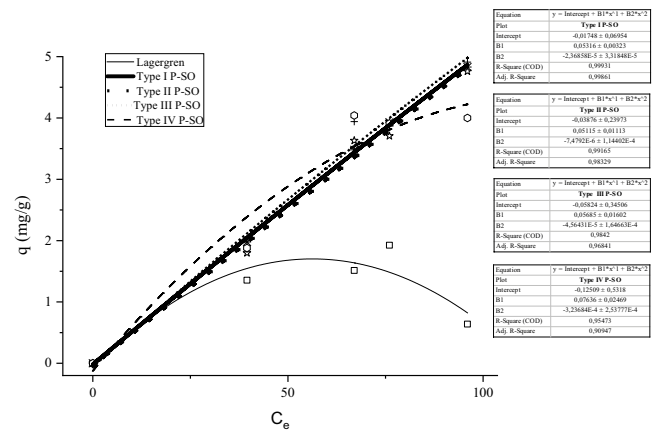
Fig. 5. Rate kinetics of Cd(II) with most commonly used models.

Table 1
Rate parameters and correlation constants

Concentration (mg L^{-1})	Pseudo-first-order		Pseudo-second-order				Elovich		
	K_L	R^2	q_e	k_2	$k_2 q_e^2$	R^2	β	α	R^2
50	0.071	0.85	1.98	0.428	1.65	0.99	0.722	1.536	0.94
100	0.125	0.96	3.93	0.168	2.60	0.99	0.478	2.583	0.87
150	0.180	0.96	3.48	0.395	4.81	0.99	0.471	2.541	0.57

the experimental data. The Langmuir equation can be written in the form below.

$$q_e = \frac{Q_{max}K_L C_e}{1 + K_L C_e} \tag{11}$$

Here C_e is the equilibrium concentration (mg L^{-1}), q_e is the amount of adsorbed metal ions (mg g^{-1}), Q_m is the maximum metal adsorption per gram of adsorbent, and K_a is the adsorption equilibrium constant (L mg^{-1}). The Freundlich isotherm can be given in the form below.

$$q_e = K_F C_e^{1/n} \tag{12}$$

where K_F and $1/n$, are the model constants indicating at Freundlich isotherm, the relative adsorption capacity of the adsorbent (mg g^{-1}) and the adsorption density, respectively. The Temkin isotherm model accepts that the decrease in adsorption heat is not logarithmic, as in the Freundlich isotherm, implies heat reduction linearly [65]. The Temkin isotherm can be expressed as:

$$q_d = \frac{RT}{b_T} \ln\left(A_T C_d\right) \tag{13}$$

where b_T and A_T are the Temkin isotherm constants, R is the universal gas constant (8,314 J k^{-1} mol^{-1}), C_d is the concentration of metal (mg L^{-1}) remaining after adsorption of solution at equilibrium and T is the temperature (K). Langmuir, Freundlich and Temkin isotherms were applied to the experimental data. The maximum adsorption capacity (Q_{max}) of C_d has not been calculated because the Langmuir isotherm has a low correlation ($R^2 > 0.1$). The Freundlich isotherm has a fairly high correlation ($R^2 = 0.99$) (Fig. 6). Adsorption capacity (K_F) was calculated as 19.94 (mg g^{-1}) and the coefficient indicating isotherm compliance was determined as $n = 1$. With regard to this value, it is accepted that adsorption is convenient when $n > 1$ [66]. In the cadmium solution, a maximum recovery of 76% was obtained at a pH of 5.8 at approximately 90 min and at an initial concentration of 100 mg L^{-1}. The Freundlich isotherm was determined as the isotherm with the highest correlation (99.9%) when the obtained data were applied to two- and three-parameter equilibrium isotherms (Langmuir, Freundlich, Temkin and Sips).

The maximum adsorption capacity (K_F) of cadmium using the Freundlich isotherm was determined to be 19.94 mg g^{-1}. At the beginning of the study, the highest Cd recovery yield per adsorbent was 46%, 22.8 mg g^{-1} at 500 mg L^{-1}. However, when removal efficiencies were taken into account, the highest value was obtained at 100 mg L^{-1} as 76%. At high concentrations adsorbent amount is fairly close to the K_F value expressed in the Freundlich isotherm. Remove cadmium from aqueous solutions was observed by four materials by Benaïssa [67]. Bean peel was maximum adsorption capacity of 147.7 mg g^{-1} followed by peas peel (118.9 mg g^{-1}), fig leaves (103.1 mg g^{-1}) and medlar peel (98.1 mg g^{-1}). Reports are also available for the use of banana and orange peels [68]
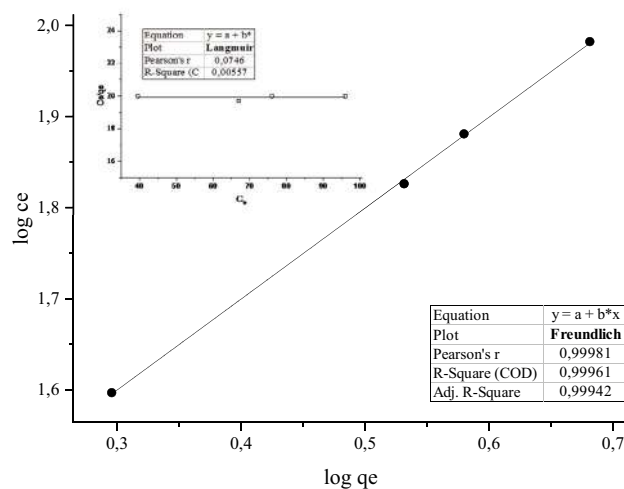

Fig. 6. Freundlich isotherm.

to remove cadmium. Table 2 shows different studies with various adsorbents.

3.8. Effective mechanisms of cadmium removal and removal efficiency

The fact that the adsorbent has a very low surface area indicates that the physical adsorption process is limited. Physical adsorption is a result of a relatively weak interaction. Physically adsorbed molecules can spread along the adsorbent surface and are typically not bound to a specific location on the surface. Due to the weak bonding, physical adsorption is easily reversed [91]. Physical adsorption is reversible in the thermodynamic sense. Chemical adsorption is caused by the chemical bonding of the substance by the atoms in the surface of the adsorbent. Chemical adsorption is an irreversible process because of strong bond formation. Chemical adsorption requires high temperatures (>10 kcal mol^{-1}) and is not reversible in thermodynamically. In addition, at the desorption study performed a limited amount of metal desorption at the end of five cycles with deionised water (<2%–3%). Chemisorption typically occurs even at very low concentrations, and the chemisorbed species are often irreversibly bound to the surface, i.e., they will not readily desorb under ambient temperature conditions [92]. This kind of waste materials generally consists of lignin and cellulose as main components. The functional groups are: acetamido groups, carbonyl, phenolic, structural polysaccharides, amido, amino, sulfylcarboxyl groups, alcohols and esters [93,94]. These groups have the ability to bind heavy metal by replacement of hydrogen ions for metal ions in solution or by donation of an electron pair from these groups to form complexes with the metal ions in solution. The reason for good cadmium removal despite the low surface area in this process suggests that this kind of binding may be present.

4. Conclusions

Potato peels, which are waste and easy to obtain, can be used as a cheap adsorbent alternatively. However, the

Table 2
Studies of the adsorption of Cd(II) using different materials

		Materials	Modification	pH	Q_{max} (mg g^{-1})	References
Agricultural wastes	Biosorbents	Apple peels	–	5.5	0.8	[69]
		Orange peels	–	7	40	[69]
		Rice husk	–	6	21.28	[70]
		Sunflower plant	–	6	35.97	[71]
	Pyrolysis	Switchgrass (*Panicum virgatum*)	KOH	6	34	[72]
		Exhausted coffee	Formaldehyde-modified	5.5	24.69	[73]
		Nutshell	Prepared Act. Car (PAC)	6	95.5	[74]
		Ceiba pentandra hulls	Steam activation	6	7.5	[75]
Marine Materials	Algae	Red algae *Galaxaura oblongata*	–	5	85.5	[76]
		Green algae *Ulva lactuca*	–	5	29.2	[77]
		Brown algae *Pelvetia canaliculata*	–	4.5	140	[78]
	Chitosan	Natural chitosan	–	6	10	[79]
		Ca(II) imprinted chitosan microspheres	–	5	49.9	[80]
		Chitosan/sporopollenin microcapsules	–	5.5	86.56	[81]
		Poly(itaconic acid)-grafted chitosan	–	5	405	[82]
Other materials	Rocks, schist, hazardous waste	Sludge of drinking water treatment	Enrichment with humic acid and Ferrous	6	5.3	[83]
		Perlite	–	6	0.64	[84]
		Volcano ash	–	9.2	0.244	[85]
		Waste sludge	–	6.3	15.73	[86]
Forestry and wood wastes	Cone, dust, leaf, needle	Pine bark (*Pinus pinaster*)	–	3.4	4.43	[87]
		Chestnut bur	–	4	16.18	[88]
		Pine needle	–	4	9.31	[88]
		Sawdust (*Cedrus deodara* wood)	Sodium hydroxide	5	73.62	[89]
		Sawdust (*Pinus sylvestris*)	Formaldehyde in Sulfuric acid	5.5	9.29	[90]
Waste		Potato peels	Non-modified	5.8	22.8	This study

unmodified potato peels provide good removal efficiency after a simple drying, making such low-cost waste materials more attractive in water and wastewater treatment. The low surface area of the potato peels shows that the adsorption is under the different impacts, although the physical hold is limited. Adsorption are partially chemical adsorption, and there are also some indications of physical adsorption in this study. It was concluded that boundary layer diffusion (film diffusion) and intra-particle diffusion rates are also partly limiting adsorption. Changes in rate models the relationship between the adsorption density in the Freundlich isotherm and the adsorbent were also observed at kinetic model.

Acknowledgement

Symbols

A_T	—	Temkin constant
b_T	—	Temkin constant
C_0	—	Initial Cd(II) concentration, mg L^{-1}
C_d	—	Concentration of metal (mg L^{-1}) remaining after adsorption of solution at equilibrium
C_e	—	Equilibrium concentration, mg L^{-1}
C_t	—	Substance concentration at any time, mg L^{-1}
K_a	—	Adsorption equilibrium constant for Freundlich, mg L^{-1}
K_F	—	Model constants indicating the relative adsorption capacity of the adsorbent, mg g^{-1}
k_L	—	Speed constant for the pseudo-first-order, min^{-1}
k_p	—	Intra-particle diffusion coefficient, mg g^{-1} min$^{-0.5}$
m	—	Adsorbent weight used in the experiment, g
n	—	Freundlich constant
Q_m	—	Maximum metal adsorption per gram of adsorbent, mg g^{-1}
q_t	—	Amount of metal ions adsorbed per unit weight of adsorbent, mg g^{-1}
R	—	Removal efficiency, %
R	—	Universal gas constant, 8,314 J K^{-1} mol^{-1}
S	—	Specific surface area for mass transfer
T	—	Temperature, K
V	—	Volume of solution used in the experiment, ml

α	—	Initial Cd(II) sorption rate, mg g^{-1} min^{-1}
β	—	The desorption constant, g mg^{-1}
β_L	—	External mass transfer coefficient, cm min^{-1}
A_T	—	Temkin isotherm equilibrium binding constant, (L g–1)
b_T	—	Temkin isotherm constant

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