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Cadmium(II) removal from aqueous solution by activated carbon of India shrub wood: optimization, equilibrium and kinetic modeling

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ABSTRACT

Applying easily available, cost-effective and environment friendly adsorbent for removal of pollutants form water has been ongoing research for last decades. The efficiency of new adsorbent that was prepared by India shrub wood for cadmium(II) removal was investigated using response surface methodology (RSM) via Design-Expert (version 7.0.0) software in building an empirical model and statistical analysis, which include the optimization of operating conditions and the study on the interactive effects of experimental factors. The characterization of this new adsorbent carried out using BET, FT-IR, SEM and pH determination at zero point of charge (pH_{ZPC}). Seventy-eight runs of designed experiments considering the interactive effect of four operative parameters as main variables. The developed quadratic model predicted optimum condition at pH 7, absorbent dose 7 g/L, adsorbate 65 mg/l, and reaction time 50 min that dye removal was 84%. The results showed that all variables solely or in combination with each other seriously affect the removal of cadmium. The fitting experimental data with models disclose the applicability of both isotherm models Langmuir model and Freundlich model for their well presentation and description. Kinetic real rate of adsorption at most conditions efficiently can be represented pseudo-second order.

Keywords: Wastewater; Heavy metals; Adsorption; Optimization; Kinetic

1. Introduction

The different developed methods which are used by researchers in order to remove the heavy metals in aqueous solutions are chemical precipitation process, chemical oxidation, filtration, reverse osmosis, electro dialysis, ion exchange and adsorption using activated carbon [1]. These methods have significant disadvantages including incomplete removal of metals, expensive monitoring and special equipment, high energy demand, the production of toxic sludge and by-products [2]. In addition, these methods are ineffective when the concentrations of metal ions in aqueous is ppm. Due to the existing problems, the adsorption process has been introduced as an alternative which uses materials such as biological derivations like bacteria, fungus, yeast, algae, composting materials and agricultural wastes [3]. Cadmium is one of the most heavy metals that have been always considered by the health experts which is because of toxicity in low concentration, its indissolubility and its widespread entrance from natural and man-made resources into the environment [4]. Today adsorption is a well-known process and an effective way to remove the water pollution. The adsorption process in comparison with other techniques has a simple design, high flexibility, easy operation and insensitivity to toxic contaminants. In addition, in this method the adsorbed pollutant (if it is appropriate) can be recycled [5]. The famous activated carbon has the most use in adsorption process which has high capacity and high adsorption level but some problems like high cost of production, the need to experts and its reactivation has led to that using it as a cost effectiveness adsorbent [6]. On the other hand, the adsorption has always been considered

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by the researchers as an appropriate method which is simple, low cost and effective for removal of heavy metals ions at low and medium concentrations [7]. In order to solve the above mentioned shortcomings, researchers are looking for developing native and cheap adsorbent, which has more efficiency and affordability, so they have a large-scale economic justification and can be use instead of standard activated carbon.

In the present study, the effect of initial concentration, adsorbent dose, contact time and pH on cadmium(II) removal from aqueous medium by PAC examined using Design Expert Version 8. The experimental data analyzed by fitting to a second order polynomial model, which was statistically validated by performing analysis of variance (ANOVA) and lack-of-fit test to assess the significance of the model. Moreover, cadmium(II) adsorption also studied with the aspect of variables optimization, kinetics and isotherms.

2. Material and methods

2.1. Carbon preparation

The Indian shrub wastes collected from Sabzevar forest in the north east of Iran. After initial preparation, raw materials used for production of activated carbon. All branches washed by water in order to clean up the wastes. In the next step, the branches cut into smaller pieces (1 cm) and these small pieces washed with distilled water several times. According to the goals of this study, the required amount of prepared branches transferred into a programmable electric furnace (Naberterm, America) under N_2 gas at the temperature of 550°C for 1 h.

For chemical activation, 0.2 g of ammonium chloride (NH_4Cl) added for each 10 g of coal, and then the coal mixed with 100 ml distilled at 100 rpm for 2 h. The solution filtered by Whatman filter paper and then the filtered coal kept in the temperature of 105°C for a half of a day. Then for the purpose of thermal activation, the Chinese bushes were filled up to 1/3 by dried coal and were kept for 2 h in the temperature of 800°C according to method has been used by Kobya [8] and Auta [9]. The prepared ash was stored in suitable sealed containers. At each test, the desired doses of coal powder (1–13 g) were used in the adsorption process tests.

2.2. Batch adsorption studies

Based on previous studies and preliminary study the range of variables namely adsorbent dosage (1, 4, 7, 10 and 13 g/L), and adsorbate concentration (5, 25, 45, 64, 85 mg/L), pH (3, 5, 7, 9 and 11) and contact time (10, 30, 50, 70 and 90 min) have been determined for modeling and optimization study. Batch studies conducted in a shaker at 200 rpm for all experiments that using 100 ml of synthetic solution at the aforementioned range of variables. Samples at the end of each runs taken and centrifuged at 10000 rpm for 15 min. The concentration of remaining ions of hexavalent cadmium in the solution after the adsorption process was analyzed using atomic adsorption spectrometry (Shimatsu model AA680). Each sample was repeated three times to minimize errors [10]. The equilibrium adsorption capacity calculated using the equation below:

$$q_e = \frac{(C_o - C_e)v}{M}$$

Where q_e (mg/g) is the equilibrium adsorption capacity, C_0 and C_e are the initial, and equilibrium concentration (mg/L) of Cr(VI) ions in solution, V (L) is the volume and M (g) is the weight of the adsorbent.

2.3. Statistical analysis and optimization

The experimental design carried out by DOE software (version 7). This software is able to limit the systematic errors by estimating the tests so that it can minimize the experiments and provide a model based on the experiments. In this study, four independent variables such as contact time, the adsorbent dose, pH and the initial concentration of metals were considered as the main variables affecting the adsorption. Optimizing these factors can have a significant effect on the efficiency of adsorption process and it can reduce the treatment costs. For this reason, RSM uses CCD through the DOE software to create an experimental model and statistical analysis applied. The adsorption process with various concentrations of adsorbent material and other major variables was designed based on CCD at 30 runs (Table 1). Finally, the experimental model and statistical analysis (ANOVA) performed by recording the obtained data in DOE software. Repetitions presented only once in some designs, therefore the number of repetitions in the pivot points increased to three times in order to increase the validity of the results. Therefore, the number of runs increased to 78.

3. Results and discussion

3.1. Chemical properties of carbon

A FTIR spectrum used to determine and study the functional groups of the adsorbent. The results of the spectrum show that the adsorbent level has different functional groups. In addition, the transmission rate of the standard activated carbon (SAC) infrared spectrum is more than the produced activated carbon and it indicates that the adsorption rate of produced activated carbon is more than Merck activated carbon (Fig. 1). The FTIR was used to determine the adsorbent surface properties and the peaks of 3443, 2900, 2400, 1500 and 1200 cm^{-1} are significant. These peaks are the results of hydroxyl group, C-H and C≡C, carboxyl group and finally C-O band. Based on the FTIR results, the produced activated carbon shows a lower pass percent than the activated carbon, so it has a higher adsorption.

The zero point charge (ZPC) for activated carbon derived from India shrub was 7.5 pH. At pH less than ZPC, the activated carbon level has a positive charge and at pH higher than ZPC, the activated carbon has a negative charge. Therefore, for pH values that are higher than ZPC, the adsorption of positively charged metals on activated carbon that has a negative charge is highly like electrostatic gravity. If pH values are less than ZPC, the adsorption of positively charged ions on positively charged carbon is

Table 1
Results of experiments according to CCD for five-level factorial of variables

No.	Variables				Residual (Cd mg/L)	Removal %
	Factor 1	Factor 2	Factor 3	Factor 4		
	A: pH	B: Initial concentration (mg/L)	C: Contact time (min)	D: Adsorbent dosage (g/L)		
1	7	45	30	7	10.04	77.67
2	3	85	90	13	14.57	82.86
3	9	45	50	7	10.14	77.47
4	7	45	50	7	10.69	89.3
5	3	5	90	1	2.90	41.93
6	7	45	50	7	10.30	77.57
7	5	45	50	7	4.20	95.43
8	7	65	50	7	10.32	84.12
9	11	5	90	13	0.22	95.47
10	11	50	90	1	0.08	99.26
11	3	5	90	13	40.67	59.33
12	11	5	10	13	0.11	97.89
13	7	45	50	7	9.83	90.5
14	11	5	10	1	0.05	98.96
15	7	25	50	7	10.04	59.83
16	11	85	10	1	0.12	99.85
17	3	5	10	1	2.92	41.66
18	3	85	10	13	15.09	82.24
19	3	85	90	1	19.86	76.63
20	11	85	90	1	0.05	99.94
21	7	45	70	7	10.05	77.65
22	7	45	50	7	10.03	77.69
23	11	85	90	13	0.02	99.97
24	11	85	10	13	0.08	99.90
25	7	45	50	4	11.31	74.86
26	7	45	50	7	11.31	74.86
27	7	45	50	7	11.35	74.81
28	3	5	10	13	57.27	2.11
29	7	45	50	10	78.38	9.7
30	3	85	10	1	62.26	21.74

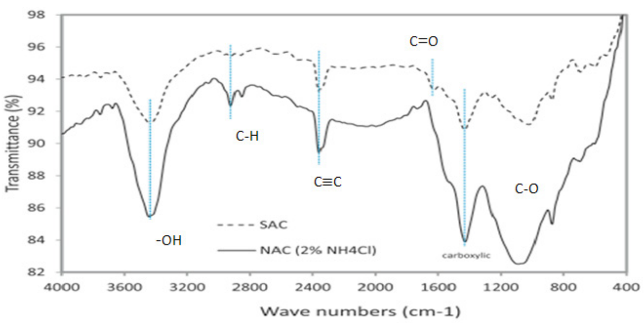

Fig. 1. FT-IR spectrum of India's shrub produced activated carbon (NAC or PAC) and standard activated carbon (SAC).

conducted, so the chemical bonding with enough energy is formed to overcome the electrostatic repulsion forces between the positive charged ions and the level of activated carbon (12).

3.2. Carbon characterization

The structural specifications including special surface, the volume of porosity and the average diameter of the porosity of produced adsorbents analyzed using adsorbing nitrogen gas and the BET isotherm adsorption model. The results showed that the adsorbent has a high special surface, which its value for produced carbon is 1029 m^2/g (Table 2). The results of the specifications of

Table 2
The BET surface area of activated India's shrub wood

Parameter	Value
Specific surface, m^2/g	1029
Pore volume, cm^3/g	0.633
Size monolayer, cm^3/g	236.4
Average pore diameter, Nm	2.46
BET, m^2/g	1088.7

produced adsorbent by heat and ammonium chloride show that the analysis of the adsorbent surface using the nitrogen gas adsorption technique and by the BET isotherm methods for activated carbon is 1024 m^2/g. The result of this study is largely consistent with the study of Sudaryanto et al. [11] and it shows 1108 m^2/g in the temperature of 650°C and within two hours as the carbonization time.

An image by a scanning electron microscope was prepared to study the morphology of the adsorbent surface. The results show that the produced activated carbon has a shape like compressed and porous fibers with a series of parallel and long channels (Fig. 2). The scanning electron microscope is a good tool for examining the morphology and the adsorbent appearance [12]. In the scanning microscope image of the adsorbent, the presence of particles with a porous and layer structure can be seen well. The results show that the produced activated carbon has a porous and layer structure that indicates the ability to remove metals favorably (Fig. 2). In addition, ammonium has an explosive property in high temperatures and it increases the porosity in produced carbon.

3.3. Development of mathematical model

The central composite design (CCD) used to find out the relationship between process responses and variables, and the results analyzed using the RSM model. In the RSM model, the relationship between the removal efficiency of the studied parameters and the variables (initial concentration, contact time, adsorption dose, and pH) is analyzed at a 95% confidence interval for the cadmium adsorption. All P-values obtained for removal of metals indicate that the sentences in the discussed models are meaningful ($P < 0.05$). Measuring accuracy is an indication of the error rate in the experiments, and the ratio is greater than 4 that is desirable in all experiments performed to remove metals from the adsorbent by more than 4. The accuracy of cadmium removal in this study was 37.38 and the linear regression coefficient between tests was 0.97 for cadmium in this study (Table 3). In this study, the optimum initial concentration, pH, adsorbate dose and contact time for cadmium sorption were determined to be 65 mg/L, 7, 10 and 50 min, respectively. The results of optimization of variables according to the standard for wastewater discharge into surface water for cadmium(II) 0.1 mg/L was investigated. This study shows that these standards can be accessed with applied adsorbent in the optimized range of variables.

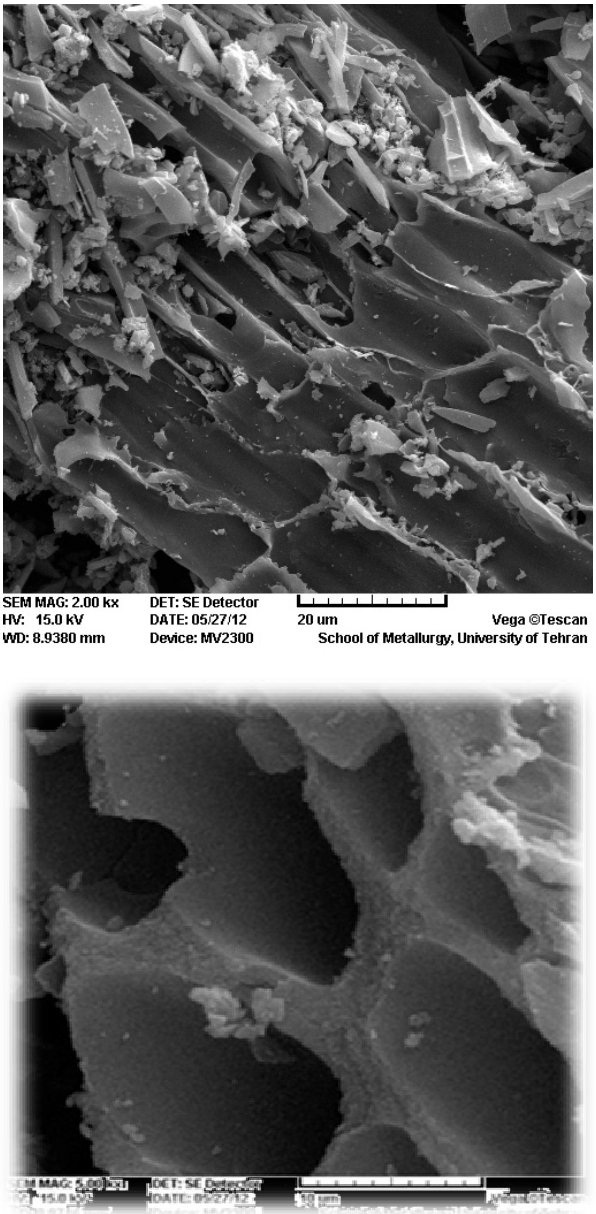

Fig. 2. Scanning electron microscope photographs of prepared activated carbon.

3.4. Effect of pH

The adsorption of cadmium decreased when the pH value of initial solution increased from 3 to 5. According to Fig. 3, the highest removals of 97.4% obtained while pH was 3 and at pH higher than 5 the adsorption efficiency decreased to 88.7%. Results show the pH variation significantly influenced the removal efficiency of Cd. As result, the percentage removal of cadmium at pH 11 has the lowest value (10.7%). At higher concentration of H^+ in the solution, protons compete with cadmium(II) ions for the adsorption sites and as a result the cadmium adsorption decreases [13]. Increasing adsorption by increasing pH indicates that positive load metal cations are less adsorbed by oxide surfaces at high pH. Increasing pH of the system reduces some of

Table 3
Regression results from analysis of Indian absorbent data on cadmium removal (II)

Factor	P	Significant/ not significant
A	>0.001	Significant
B	0.001>	Significant
C	0.001>	Significant
D	0.001>	Significant
AB	0.4	Not significant
AC	0.03	Significant
AD	0166	Not significant
BC	>0.001	Significant
BD	0.65	Not significant
CD	>0. 01	Significant
A^2	0.617	Not significant
B^2	0.245	Not significant
C^2	0.151	Not significant
D^2	0.003	Significant
Model	>0.001	Significant

Cadmium Removal by AC (%) = $-4.25A - 9.07B + 6.60C + 25.39D + 0.68AB - 1.76AC - 1.12AD + 2.73 - 0.40BD + 2.12CD + 3.94A^{2-} - .19B^{2-} - 1.39C^{2-} - 3.87D^2 + 89.32$

R-squared	Adj R-squared	Pred R-squared	Adeq precision
=0.972	= 0.997	= 0.995	= 37.314

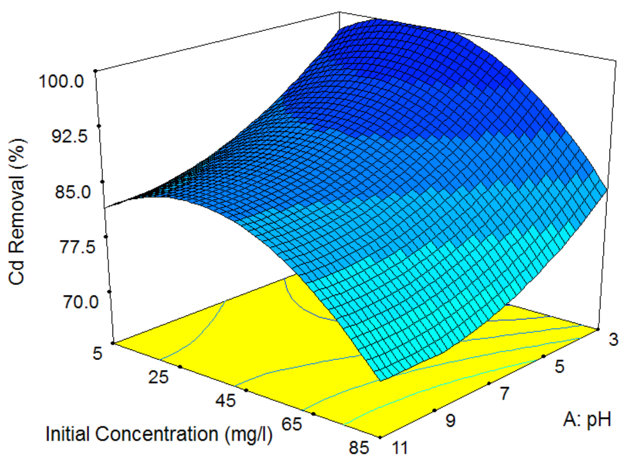

Fig. 3. Response surface plot showing the effect on Cd ions concentration and pH and their mutual effect on the metal uptake.

positive-charge sites and increases the number of negatively charged sites on the adsorbent site. Apparently sites with negative load are more preferable to adsorb cadmium ions by electrostatic adsorption [13]. The statistical analysis of the data also confirms that pH variations with $P < 0.001$ have a significant effect on the adsorption efficiency of the cadmium. The main reason for reducing the removal efficiency of these metals by increasing pH should be investigated in changing the flux charge on the adsorbent surface which is related to the active agent groups on this surface [14]. On the other hand, the adsorption of these positively charged metals on activated carbon in acidic pH that has positive load should be related to a chemical bond with enough energy that is formed by overcoming the electrostatic repulsion force between the positive charge ions and the surface of activated carbon [15]. However, several researchers have investigated the effect of pH on adsorbing the concentration of cadmium ions on the different adsorbents that can be referred to their results. Bishnavi et al. [16] found the maximum chromium removal of activated carbon of rice hall and also the activated carbon with alumina respectively at pH 2 and pH 4. Wang et al. [13] pointed to the maximum adsorption of cadmium(II) ions from aqueous solution by the cheap bamboo coal adsorbent in pH 12, which contradicts with the results of this study. These researchers have argued that the reasons of reduction in adsorption in acidic environments are the high concentrations of hydrogen ions in the solution and also their competition with cadmium for replacing on adsorbent sites. The studies of Karthikeyan [17] indicate that the low level of pH increases the H^+ ions in the surface of carbon and this will result in a strong electrostatic gravity between the positive charge of the surface of activated carbon and the cadmium ions.

3.5. Effect of initial concentration

The effect of initial concentration of Cd on the adsorption efficiency in the range of 5–85 mg/L was investigated. The results show at the highest concentration of Cd (85 mg/L) the efficiency of system decreased. Fig. 3 represents high ability of prepared activated carbon for remove low concentration of Cd (5 mg/L) with 93.9% adsorption removal and 76.5% at 85 mg/L of adsorbate. The results show a significant difference among applied adsorbate concentration with p value = 0.001. The reason is that probably the adsorption sites are specific and limited in adsorbents, so that there are more available adsorption sites in the adsorbent surface at lower concentrations [18]. It causes that the metals have been quickly adsorbed and the removal efficiency increases. However at higher concentrations especially at the concentration of 85 mg/L, increasing the adsorbent on the adsorbing sites rapidly saturates the high surfaces on the adsorbent and decreases the removal efficiency of the adsorbent [13]. The main reason for this issue is the effect of concentration on the adsorption rate which is due to the density of atoms of these metals in solution at high concentration [19]. So more pressure will be created on the adsorption of these metals and also it causes that metals be adsorbed even in more than one adsorption layer [20]. The studies of Polivan et al. [21], Wang et al. [13] and Bishnavi et al. [16] confirm the results of present study.

3.6. Effect of adsorbent dose

The relation between the contact time and the adsorbent dose is shown in Fig. 4. So that the incremental trend up to 50 min is tangible and evident. Then the performance will be almost constant and they have decreasing trend by increasing the doses of adsorbent to doses higher than 50 min. So that the removal efficiency of cadmium(II) was 97.8% while the adsorbent dose was 7 g/L. While the removal efficiency for 1 g of adsorbent was 10.6% and it indicates that increasing the adsorbent dose increases the removal efficiency.

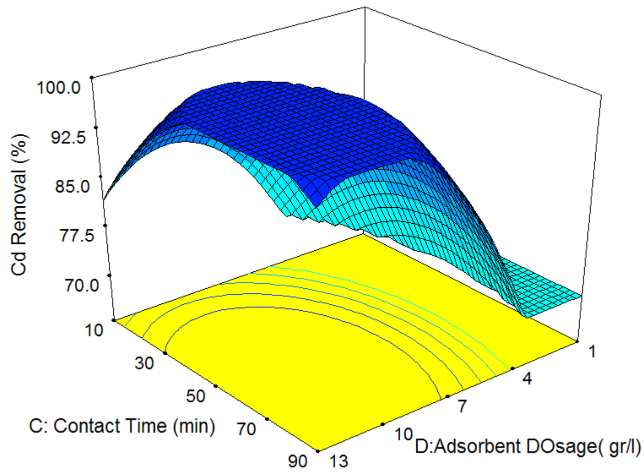

Fig. 4. 3D plot showing effect of adsorbent dose and contact time on percentage adsorption of Cd(II) ions.

In addition, there is a significant difference between the removal efficiencies of cadmium(II) based on the adsorbent dose with $P < 0.001$. Increasing the amount of adsorbent can cause increasing surface and also more accessibility of metal molecules to adsorbing points at the adsorbent surface [22]. On the other hand, increasing the adsorbent dose means faster adsorption of metals from the solution and reducing the adsorbent concentration in the solution. This reduces the available metals for creating maximum surface coating which will reduce the amount of adsorbed ions per unit of weight of the adsorbent [12]. The results of the direct correlation between the increases in adsorption dose and the increases in the percentage of metal removal in the studies of Wang et al. [13], Gupta et al. [23], and Croweeka et al. [24] are consistent with the results of this study.

3.7. Effect of contact time

Fig. 4 shows that the adsorption efficiency of cadmium(II) at the contact time of 50 min had the highest removal rate of 87%, and vice versa at the contact time of 10 min has the lowest removal rate of 42%. The results of this study showed that the percentage removal of adsorbed metal was directly related to the contact time, so that the removal of cadmium(II) increases from 10.6% at the contact time of 10 min to 93.9% at the contact time of 90 min. The average removal rate of metals based on different contact times with $P < 0.001$ shows a significant difference. Indian shrubs like the other natural adsorbents, at the beginning of the adsorption process, the rate of adsorption increases that is because of the large number of adsorption sites, the large difference in the concentration between adsorbed material in the solution and its amount on the surface of the adsorbent. However, over time, the slope is very gentle which is due to the presence of an adsorbing layer on the adsorbent surface. Also over time, it is difficult to occupy the remaining surfaces because there is repulsion between adsorbed metal on the surface of the adsorbent and the molecules in the solution phase. So that the results showed that during the first 30 min of the reaction, more than 80% of cadmium is removed by the adsorbent. This suggests a better adsorbent performance versus the Merck absorber at the same time. It means that in cases where less adsorbing time is considered, the activated carbon of India shrubs are preferred to the activated carbon of the Merck Company. The results of this study have been compared with the studies of Wang et al. [13] that states the rate of metal adsorption was rapid in early stages. So that about 40% of total cadmium was removed in the first 5 min and the amount of adsorption for cadmium(II) ions by bamboo coals at the initial concentration of 100 mg/L was 18.20 mg/g after 6 h as the equilibrium time [13].

3.8. Optimization of experimental conditions

One of the main objectives of this study was to find optimum parameters for maximum adsorption of cadmium(II). Graphical optimization removal of cadmium(II) (Fig. 5) based on two variables pH and initial concentration shows the activated carbon made from India shrubs at the pH lower than 6 and the initial concentration of metals less than 65 mg/l in the range of yellow tape can provide the standards of wastewater discharge into receptive water. This graph also shows that the range of 50–70 min for contact time and the adsorbent doses between 10–13 g, which are in the range of yellow tape, can supply the standards of wastewater discharge into receiving water.

3.9. Adsorption isotherms

The results of the correlation coefficients for removing cadmium(II) by the activated carbon produced from India shrubs show that the process of adsorbing this metal follows both Freundlich (a) model and Langmuir (b) model, but it is more correspondents with Freundlich model:

$$q_e = K_f C^{1/n} \quad (1)$$

So that q_e is the equilibrium adsorption capacity of the adsorbent in milligrams of cadmium per gram of the adsorbent, C_e is the equilibrium concentration of cadmium ions in milligram per liter, k_f and $1/n$ are respectively the constants related to adsorption intensity and capacity.

In addition, the equilibrium model of Langmuir is used in the adsorption process according to Eq. (2):

$$q_e = q_{max} bC_e / 1 + bC_e \quad (2)$$

q_e is the equilibrium adsorption capacity of the adsorbent in mg Cd/g of the adsorbent, C_e is the equilibrium concentration of cadmium ions in mg/L, q_{max} is the maximum adsorbed metal in mg cadmium/g of adsorbent and b is a constant that expressed the binding energy of adsorption in mg/L.

The nonlinear regression analysis equation has been used to determine the constants of the Freundlich and Langmuir equations in SPSS software [25]. In this study, the Langmuir and Freundlich correlation coefficient for cadmium was respectively 0.96 and 0.99. According to the results, the n value was 2.5 for cadmium metal, which shows the heterogeneous adsorption process. This means that the process of

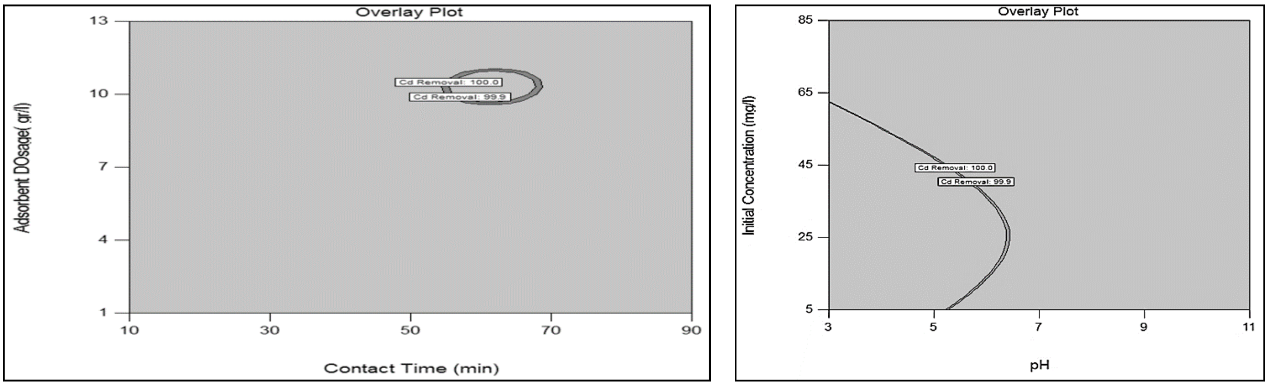

Fig. 5. Overlay plot for optimal area of effluent cadmium(II) concentration at optimized pH and initial concentration of adsorbate.

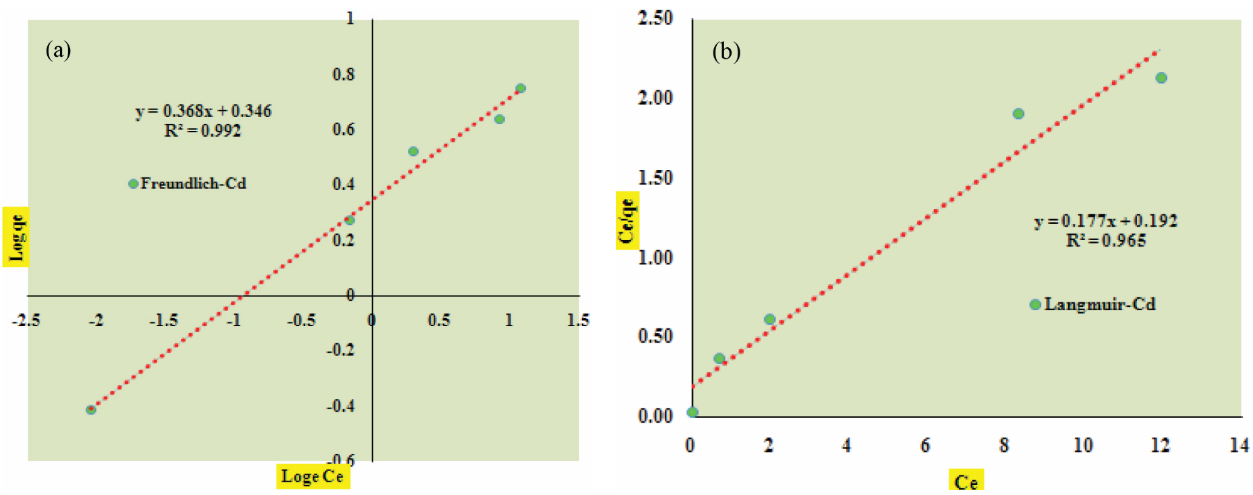

Fig. 6. Freundlich Isotherm (a) and Langmuir isotherm (b) for the adsorption of Cd onto prepared AC.

metal adsorption occurs in heterogeneous sites, but a single-layer adsorption occurs on the adsorbent surface. On the other hand, the intensity of metal adsorption by the adsorbent is also desirable. These data are shown in Fig. 6.

3.10. Adsorption kinetics

The adsorption kinetics is one of the important information for understanding adsorption mechanism and for assessing the performance of adsorbents. The pseudo second order model assumes that two reactions are effective in adsorbing adsorption one adsorbent in parallel, the first one is fast and it will quickly continue to equilibrium state [26]. The pseudo-first order model is shown in Eq. (3) [27].

$$dq/dt = k_1 (q_e - q) \quad (3)$$

where q_e is the equilibrium level of metal ions adsorption on the biological adsorbent in terms of mg/L, q is the amount of metal ion adsorption on the biological adsorbent in each of the studied periods and k is the constant of a pseudo-first order equation. Integration of this equation in time intervals of $t = t$ to $t = 0$ and for the adsorption rate of $q = 0$ to $q = q_0$ results the relation 4.

$$\text{Log } (q_e - q) = \log q_e - k_1/2.303{*}t \quad (4)$$

By drawing the logarithm equation of the difference of the equilibrium adsorption and adsorption in any time [log $(q_e - q)$] vs. time (t), if the resulting curve has a linear state, the adsorption kinetics follow this model. The pseudo-second order equation is based on this assumption that the biological adsorption follows a second order mechanism, which means that the rate of using adsorbing sites is directly related to the number of used second order sites. Relation 5 shows this mode

$$\Delta p/dt = k_2 (q_e - q_0) \quad (5)$$

where k_2 is the constant adsorption rate in second order form in terms of gram per milligram in minute. Integration this equation in time intervals $t = 0$ to $t = \text{t}$ and in adsorption rate of $q = 0$ to $q = q_e$ and then by linearizing it shows the relation 6.

$$t/q = 1/k_2 \cdot q_e^2 + 1/q_e{*}t \quad (6)$$

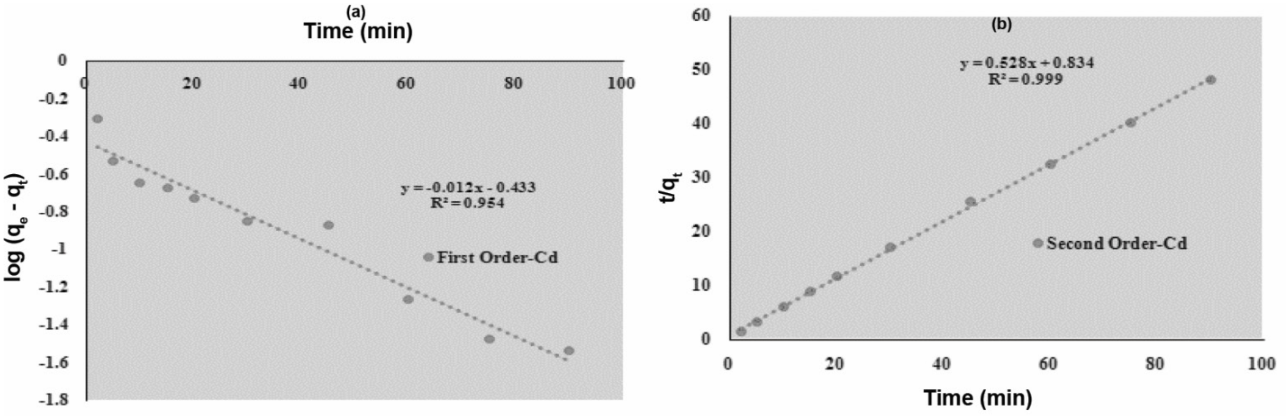

Fig. 7. Pseudo-first-order (a), and Pseudo-second-order (b) kinetic plot for the adsorption of Cd(II) Conditions.

The values of q_e and k_2 are obtained according to drawing a linear curve (t/q) vs. time (t) [28]. Fig. 7 shows that the results of the values of correlation coefficients of removing cadmium(II) by produced activated carbon from Indian shrubs follow both first order (a) and second order (b) kinetic models but it is more correspondent with the pseudo-second order model. The results of the linear regression coefficient for pseudo first order and pseudo second order adsorption kinetic models showed that the cadmium adsorption process follows the pseudo second order kinetics more (Table 3). The kinetic results of this study are consistent with Singh et al.'s findings [29].

4. Conclusions

This study obviously confirmed the applicability of activated carbon of India shrub wood for cadmium removal. The maximum removal (99.97%) was achieved when absorbent does was 13 g/L. The modeling and statistical analyzing of data clearly confirmed that DOE software is a suitable method to experimental design and data analyzing. Sufficient models based on the experimental results of CCD and RSM were employed to understand better the direct effect of main factors namely pH, absorbent dose, adsorbate concentration, and reaction time on the process. Different kinetic models were also investigated, and the pseudo-second order was found to be the appropriate kinetic model in this research work. The Langmuir and Freundlich isotherm models were tested for the explanation of the adsorption equilibrium of cadmium. The results were in good agreement with Langmuir isotherm. This study confirmed that the India's shrub wood has high adsorption capacity compared to other adsorbents.

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