Adsorption of heavy metal ions using activated carbon derived from Eichhornia (water hyacinth)

Sami D. Salman¹, Israa M. Rasheed¹, Alaa K. Mohammed¹
Biochemical Engineering Department, Al-khwarizmi College of Engineering, University of Baghdad, Baghdad 47024, Iraq.

E-mail: sami@kecbu.uobaghdad.edu.iq

Abstract. Removal of heavy metal ions such as, cadmium ion (Cd²⁺) and lead ion (Pb²⁺) from aqueous solution onto Eichhornia (water hyacinth) activated carbon (EAC) by physiochemical activation with potassium hydroxide (KOH) and carbon dioxide (CO₂) as the activating agents were investigated. The Eichhornia activated carbon was characterized by Brunauer Emmett Teller (BET), Fourier Transform Infrared spectroscopy (FTIR), and Scanning Electron Microscopy (SEM) techniques. Whereas, the effect of adsorbent dosage, contact time of pH, and metal ion concentration on the adsorption process have been investigated using the batch process technique. The kinetic data of the adsorption were fitted with the pseudo-first order and, pseudo-second-order models as well as Langmuir and Freundlich isotherm models. The results were found to be well fitted with pseudo-second-order and Freundlich models. The results also reveal that activated carbon derived from Eichhornia was an efficient adsorbent for the adsorptive removal of heavy metal ions from solutions whereas, the maximum sorption capacities of the Pb²⁺ and Cd²⁺ ions were detected as 102 and 49.5 (mg/g), respectively.

Keywords: Eichhornia, Activated carbon, physiochemical activation, Heavy metal ions

1. Introduction
One of the environmental problems is the pollution of soil, rivers, lakes, seawater, and groundwater, which results from industries waste, chemicals applied to the agricultural soils as fertilizers, and other facilities. Such applications may result in an increase of heavy metals in the soil and water. The removal of heavy metal ions from aquatic solutions is regarded as the most significant environmental problem in the present-day facing each country. Based on the recent literature surveys, its found that the heavy metals was the most common groundwater pollutants. Subsequently, low-cost materials are required to eliminate heavy metal ions from polluted water using various techniques were promoted to eliminate suspended or dissolved heavy metal from wastewater, including various conventional processing methods such as adsorption, electrodeposition process, distillation or evaporation, filtration, flotation, ion exchange, precipitation, ultrafiltration, neutralization, precipitation, sedimentation, reverse osmosis and solvent extraction [1]. Activated carbon and charcoal adsorbents are vastly used for the removal of heavy metal pollutants due to their high resulting active surface area, large mesopore and micropore and volumes. Despite their adsorption capacity for contaminant removal from aqueous solutions, the activated carbon as commercial product is unfavourable for heavy metals elimination due to its low affinity [2].
Thus, it is required to derive another adsorbent, particularly from green source materials, to eliminate the heavy metal substances from aqueous solutions. Various agricultural by-products, such as bagasse, fruit stones, nutshells, and agricultural waste produced from peanut hulls, rice, sugar cane, and date pits as well as well shell and lignocellulosic materials from wood species were studied in the last few years as untreated material or as potential precursors for ACs production using different activation processes [2]. A great number of researchers have been investigating removing heavy metals from aqueous solutions using activated carbon [3, 4]. Nowadays, the depleted source of the commercial coal-based active carbon results and their price increases have been motivated searched for substitutional activated carbon derived from numerous and inexpensive sources. Kongsuwan et al have been investigated eucalyptus phloem activated carbon for binary sorption of Cu\textsuperscript{2+} and Pb\textsuperscript{2+} ions from aqueous solution [5]. They revealed that both heavy metals were adsorbed and the maximum sorption capacities of Cu\textsuperscript{2+} and Pb\textsuperscript{2+} ions were 0.45 and 0.53 mol/kg. Guo et al. have explored the poultry grubbiness activated carbon for removal of heavy metal polluted water [6]. They found that the poultry litter activated carbon dominated with higher affinity and capacity for heavy metals adsorption as compared with commercial activated carbon manufactured from bituminous coal and coconut shells.

A previous study using commercial activated carbon in granular for Pb\textsuperscript{2+} and Cd\textsuperscript{2+} adsorption form reports that the removal efficiencies were 16.84 and 17.23 mg/g respectively [7]. The highest removal efficiency of Pb\textsuperscript{2+} and Cd\textsuperscript{2+} was reported for activated carbon manufactured from radical press cake produced in the petroleum industry. Despite their low porosity and low surface area, the activated carbon was imputed to the modulation of the adsorbent surface area by nitrogen and oxygen including functional groups during the chemical activation stage. Likewise, it’s required to study the adsorbents performance with the presence of different heavy metal ions for industrial wastewater. A new study on the adsorption of heavy metal ions under an effect in the binary system was implemented by [8] using activated carbon prepared from pecan nutshell that rich in CaCO\textsubscript{3} with chemical process activation with various reagents (CH\textsubscript{3}COOH, H\textsubscript{2}SO\textsubscript{4}, H\textsubscript{3}PO\textsubscript{4}, KCl, CaCl\textsubscript{2}, and NaCl). This study provides the researchers with ideas about the effect of chemical activation of the heavy metal ions adsorption feature, as well as the antithesis adsorption effect in the binary component system. Two activated carbon samples were prepared without and with physical activation (CO\textsubscript{2}) for comparison purposes. The effect of various uses of chemical reagents on surface area and pore volume produced using the BET technique was well observed. Generally, chemical activation enhanced the adsorption of several metal ions onto the activated carbon surface up to 1214% compared with physical activation activated carbon. The prepared activated carbons with KCl and NaCl activation showed higher performance of adsorption compared to other activated carbon samples, resultant to their large surface area as well oxygenated groups on the adsorbents. However, the results showed that only physically and chemically activated carbons have ion exchange properties.

In the present, work the adsorption of cadmium Cd\textsuperscript{2+} and lead Pb\textsuperscript{2+} ions from solutions, onto Eichhornia (water hyacinth) activated carbon in an agitated batch technique. The prepared eichhornia activated carbon was characterized by Brunauer Emmett Teller (BET) and Fourier transform infrared spectroscopy (FT-IR) techniques. The effect of the
adsorbent dosage, contact time, pH, and metal ion concentration on the adsorption capacity has been studied. The adsorption data were fitted with the pseudo first and second order models, like wise, the data were fitted also with isotherm models of the Langmuir and Freundlich.

2. Materials and Methods

2.1 Adsorbates
Reagents of Cadmium and lead nitrate salts Cd(NO\textsubscript{3})\textsubscript{2}·4H\textsubscript{2}O and Pb(NO\textsubscript{3})\textsubscript{2} with purity ≥ 99% (Sigma-Aldrich) were used for the preparation of stock solutions. The heavy metal ions stock solutions have been prepared using distilled water to obtain the desired concentration (25 – 300) mg/L.

2.2 Adsorbents
Eichhornia (water hyacinth) as raw material was collected from the Tigris river near Al-Za'franiya city, Baghdad. The raw material at first washed well and then dried overnight in an oven at 100 °C. The dried material was crushed, sieved to 5-10 mm particle size and processed to activated carbon using a physio-chemical activation in two stages; carbonization and activation. The process was carried using a stainless steel can in a resistance furnace heated to 700 °C under an N\textsubscript{2} atmosphere for 2 hours and the sample was soaked in a potassium hydroxide solution (6 M) with an impregnation ratio of 3 w/w of KOH/char. The impregnated mixture has been dehydrated for 24 hours at 105 °C and the product was activated using the same conditions of the carbonization stage, but upon the activation, the temperature was reached the flow of nitrogen gas switched off and carbon dioxide (CO\textsubscript{2}) purged for 3 hours to improve the porosity of activated carbon [9]. The produced activated carbon was washed with 0.1 M HCl to remove all residual ashes, washed with hot water to adjust pH near 7 and dried at 70 °C.

2.3 Characterization of activated carbon
The Eichhornia activated carbon characteristics such as an active surface and structure porosity were determined using a standard multi-point BET technique [10]. Nitrogen (N\textsubscript{2}) gas adsorption/desorption isotherm at 77° K and 1.0665 x 10\textsuperscript{5} N/m\textsuperscript{2} was conducted for the activated carbon samples using an automated system (BET: HORIBA, SA-900 series, USA). In addition, Fourier transforms infrared spectroscopy spectroscope (IR Affinity-1 Shimadzu, Japan) was used for surface functional groups determination.

2.4 Adsorption experiments
Single batch adsorption method for Cd\textsuperscript{2+} and Pb\textsuperscript{2+} ions was studied to evaluate the adsorption capacity of Eichhornia activated carbon (EAC). Stock solutions of 1,000 mg/L for each Cd and Pb ions were prepared by dissolving the desired amounts of nitrate salts [Cd (NO\textsubscript{3})\textsubscript{2}·4H\textsubscript{2}O and Pb (NO\textsubscript{3})\textsubscript{2}] in distilled water. The solution was diluted with distilled water to obtain the required concentration (25 – 300) mg/l. Different amounts of Eichhornia activated carbon were well mixed with 50 ml of Cd and Pb ion solutions of different concentrations and periods. The samples were filtered and acidified using HNO\textsubscript{3} for analysis. The concentrations of Cd and Pb ions of the
solutions were determined using a UV–Vis spectrophotometer (Shimadzu UV-1700, Japan). The effect of the adsorbent dosage, contact time, initial concentration, and the pH of the solution to the capacity of adsorption were investigated.

The adsorption capacity of Cd and Pb ions at equilibrium, \( q_e \) (mg/g) was calculated using the equation below;

\[
q_e = \frac{V}{W} (C_o - C_e)
\]

(1)

where \( C_o \) and \( C_e \) (mg/L) are liquid-phase concentrations of the Cd and Pb ions at initial and equilibrium conditions, respectively. \( V \) (L) is the volume of the solution and \( W \) (g) is the mass of dry adsorbent used.

Likewise, the adsorption capacity Cd and Pb ions at time \( t \), \( q_t \) (mg/g), were calculated using the equation below;

\[
q_t = \frac{V}{W} (C_o - C_t)
\]

(2)

where \( C_t \) (mg/L) is the liquid-phase concentration of the Cd and Pb ions at any time \( t \).

3. Results and Discussion

3.1 Characterization of activated carbon

The Eichhornia activated carbon characteristics such as a surface area and pores volume are illustrated in Table 1. The results are compared with IUPAC reference values less than 20Å for micropores, (20–500) Å for mesopores, and greater than 500Å for macropores [11]. It’s found that the surface area, total pore volume, and average pore diameter about 1322.24 m²/g, 0.46 m³/g, and 21.6Å, respectively. This means that physio-chemical activation enhanced the physical properties of activated carbon.

| BET surface area (m²/g) | Total pore volume (cm³/g) | Average pore diameter (Å) |
|-------------------------|---------------------------|---------------------------|
| 900                     | 0.47                      | 21.6                      |

The FTIR spectrum of Eichhornia activated carbon samples without and with heavy metal ions loaded were presented within 500-4000 cm⁻¹ as shown in Figures 1. It’s clearly noted that there are a number of adsorption peaks that indicating different functional groups [12] including water, acid, amide, alkane, alcohol, and alkene. Eichhornia activated carbon (EAC) presents an IR and around 3460 cm⁻¹ which was attributed to the bending vibration of hydroxyl (O–H) in hydrogen bonding that may be due to the presence of water [13].

The adsorption peaks around 2000 cm⁻¹ were assigned to the C≡C bond due to the presence of alkyne and the peaks around 1650 cm⁻¹, 1530 cm⁻¹ referred to C=O, C=C bonds due to the presence of Carboxylic acid and alkene. Likewise, the peaks around 1150 cm⁻¹, 950 cm⁻¹, indicated to C-O, = C-H, due to the presence of alcohol and alkenes. [14].

The adsorption of Cd and Pb on the Eichhornia activated carbon samples affected on the FTIR spectrum were some peaks disappeared and the others shifted due to the presence of new functional groups. This means that the groups were participating in the adsorption to a certain extent to
produce new functional groups as a result of complexation Cd and Pb ions with the main functional groups [15].

![FTIR spectra](image)

**Figure 1.** FTIR spectra of the activated carbon (a) without sorption; (b) with sorption of Cd ions; (c) with sorption of Pb ions

3.2 **Effect of operational factors**

3.2.1 **Effect of pH on adsorption.** The influence of pH on the heavy metal ion (Cd $^{2+}$ and Pb $^{2+}$) adsorption was studied at different pH values (3, 4, 5, 6, and 7). These values were chosen because the heavy metal ions may be precipitated in the solution at pH above 7 [16]. The effect of pH on adsorption capacity was investigated as shown in Figure 2, 50 ml of solution volume with initial heavy metal ion concentration of 100 mg/l and 50 mg of the adsorbent dose was used for investigation whereas-while 3 hours was selected as contact time at an agitation speed of 200 rpm.
Its clearly noted that the adsorption capacity of Cd²⁺ and Pb²⁺ increased with increasing pH values. This is ascribed to the state that at the lower values of pH, there is the solid competition between heavy metal ions and hydrogen ions on the surface area of activated carbon. However, the competition between H⁺ and OH⁻ ions was diminished due to the pH values increasing [17] and [18]. In addition, it is obviously noted from Fig. 2 that the adsorption capacities of Cd²⁺ and Pb²⁺ were increased with increasing of pH values from 3 to 5. Whereas, the adsorption capacity was slightly changed for pH values through 5 and 6. Additionally, adsorption capacity increased with increasing of pH from 6 to 7, especially for Pb²⁺ ions. This can indicate that the process of adsorption and deposition of metal ions as hydroxide may be occurred for in pH values greater than 6.

3.2.2 Effect of contact time. The experimental batch isotherm work was conducted at a pH value of 5 with contact time varies from 5 to 480 min, initial heavy metal ion concentration of 100 mg/L and 50 mg of adsorbent dose with 50 mL of solution at 30 °C in order to study the effect of contact time on the individual adsorption capacity of Cd²⁺ and Pb²⁺ as shown in Fig. 3. It’s clearly noted that the adsorption capacity of the heavy metals was significantly for contact time increasing from 5 to 50 min, whereas an insignificant increase was observed from 50 to 120 min and the adsorption reached the equilibrium for contact time higher than 120 min. This means that the intense adsorption of up to 50 min could be imputed to the availability of the active sites on the Eichhornia activated carbon surface. Whereas the adsorption capacity becomes languid for contact time between 50 and 120 min due to heavy metal occupation on the active, and the adsorption capacity reached saturation for the time above 120 min. Similar results for adsorption of Cd²⁺ and Pb²⁺ by activated carbon produced various agricultural waste were found by [19, 20].
3.2.3 Effect of Initial concentration. The influence of the initial concentration, the value of pH, time of contact, and the dosage of the adsorbent on the capacity of the heavy metal ions (Cd\(^{2+}\), Pb\(^{2+}\)) adsorption was studied using Eichhornia activated carbon. The heavy metal ions concentration of 25 - 300 mg/L for 180 min as contact time with pH = 5 and the dosage of the adsorbent solution of 50 mg/50 mL was illustrated in Figure 4. From this Figure, it can be noted that the capacity of adsorption for Cd\(^{2+}\) and Pb\(^{2+}\) ion was augmented with the intensity of the initial concentration (25 - 300 mg/L), whereas a gradual augmentation of the adsorption capacity with concentration intensity for initial concentration of 150 to 300 mg/L. This phenomenon could indicate that high energy sites on the surface of activated carbon prepared from Eichhornia have been saturated with the accretion of the heavy metal concentration.

3.2.4 Effect of adsorbent dosage. To verify an effect of the activated carbon dosage on the removal efficiencies of Cd\(^{2+}\) and Pb\(^{2+}\), isothermal adsorption was performed using 25, 50, 100, 200, and,
300 mg per 50 mL with initial concentrations of ions 100 mg / L, and contact time 180 minutes, as well as the value of pH 5. An effect of the activated carbon dosage on the adsorption capacity of Cd $^{2+}$ and Pb $^{2+}$ ions was illustrated as shown in Figure 5 which shows that the increase in adsorption capacity of metal ions was conducted continuously with the increase of the activated carbon dosage. Also, it can be noted that the adsorption capacity of Cd $^{2+}$ enhanced from 28.474 to 118.195 mg/g with increasing of the AC dosage from 25 mg/50 ml to 300 mg/ 50 ml. Likewise, the adsorption capacity of Pb $^{2+}$ was enhanced from 48.419 to 135.5732 mg/g with increasing in the AC dosage from 25 to 300 mg per 50 ml.

Figure 5. Effect of adsorbent dosage on the adsorption of Cd $^{2+}$ and Pb $^{2+}$

These patterns referred to that due to the increasing the adsorbent dosage, the surface area and more of the adsorption sites. Whereas further increases in AC dosage led to a marked tepidity in the adsorption capacity, this can be imputed to the equilibrium between the metal ions concentration at absorbent surface with the concentration of residual metal ions in the solution as well as adsorption sites overlap due to overcrowding of EAC particles. These results agree well with those conducted by [21] who studied the adsorption of toxic metal ions from aqueous solution using activated carbon produced from coconut shell and [22] who investigated the removal of Ni, Pb and Cu from semiconductor industrial wastewater using palm shell activated carbon.

3.3 Adsorption isotherms
The Langmuir adsorption isotherm correlation as shown in Eq. 3, was used to plot a relationship between metal ions concentration in a liquid phase ($C_e$) and in a solid phase ($q_e$) at various initial concentrations of Cd $^{2+}$ and Pb $^{2+}$.

$$\frac{C_e}{q_e} = \frac{1}{q_mR_L} + \frac{C_e}{q_m}$$  \hspace{1cm} (3)

It is found from Figure 6 that there is exquisite fitting between the experimental results and Langmuir adsorption isotherm correlation and the maximum adsorption capacities ($q_m$) were found to be 54.3478 mg/g for Cd $^{2+}$ and 99 mg/g for Pb $^{2+}$. In addition, the Freundlich isotherm correlation
as shown in Eq. 4 was used to plot the data obtained for the capacity of the adsorption at various concentrations of Cd\(^{2+}\) and Pb\(^{2+}\).

\[
\ln q = \ln K_F + \frac{1}{n} \ln C
\]  

(4)

Figure 6. Langmuir isotherm of Cd\(^{2+}\) and Pb\(^{2+}\) ions adsorption

It is clearly noted from Figure 7 that there is exquisite fitting between the experimental results and Freundlich isotherm correlation. The Freundlich model is non-uniform on the adsorbent surface and sites on the adsorbent surface have various affinity, that means that adsorption for Cd\(^{2+}\) and Pb\(^{2+}\) eventuate as multilayers on the adsorbent surface.

Figure 7. Freundlich isotherm of Cd\(^{2+}\) and Pb\(^{2+}\) ions adsorption

| Isotherm parameters | Cd\(^{2+}\) | Pb\(^{2+}\) |
|---------------------|-------------|-------------|
| q_m (mg/g)          | 58.8235     | 99          |
| K_L (L/mg)          | 0.0561      | 0.0821      |
| R^2                 | 0.9727      | 0.9804      |

Table 2. Langmuir and Freundlich isotherm parameters at 30 °C
Adsorption kinetic models

The adsorption kinetics of Cd\(^{2+}\) and Pb\(^{2+}\) at pH value of 5 with sorption time varies from 5 to 480 min, initial heavy metal ions concentration of 100 mg/L and 50 mg of adsorbent dose with 50 mL of solution at 30 °C was studied using pseudo first (PFO) order and pseudo second order (PSO) models \[23\] and \[24\].

The pseudo first-order model is given by Eq. (5):

\[
\ln (q_e - q_t) = \ln q_e - K_1 t
\]

(5)

where \(q_e\) is the adsorption capacity at equilibrium condition (mg/g), \(q_t\) is the adsorption capacity at contact time \(t\) (mg/g), and \(K_1\) is the PFO constant rate (min\(^{-1}\)).

Whereas, the pseudo second order (PSO) model is given by Eq. (6)

\[
q_t = \frac{K_2 q_e^2}{1 + K_2 t q_e}
\]

(6)

where \(K_2\) is the PSO constant rate (mg/g.min\(^{-1}\)).

The kinetic data of Cd\(^{2+}\) and Pb\(^{2+}\) adsorption were plotted and fitted with these two models as shown in Figures 8 and 9. It clearly noted that the plot of pseudo-first-order for Cd\(^{2+}\) and Pb\(^{2+}\) adsorption and the parameters of the kinetic models are not well agreed with experimental data illustrated in Table 3.

In addition, these results are well agreed with those conducted by \[25\] and \[26\] who investigated the adsorption behaviour of Cd\(^{2+}\) using sawdust activated carbon. Consequently, the experimental data for Cd\(^{2+}\) and Pb\(^{2+}\) adsorption are well fitted with the pseudo-second-order model as shown in Figure 10 and Table 3.

Consequently, the results reveal that the adsorption process of Cd\(^{2+}\) and Pb\(^{2+}\) pursue the pseudo second-order model, which indicates chemical sorption comprises electron exchange between heavy metal ions and Eichhornia (water hyacinth) activated carbon.

![Figure 8](image-url)

**Figure 8.** The pseudo-first-order kinetic model fitting for the adsorption
of Cd $^{2+}$ and Pb $^{2+}$ ions

Table 3. PFO and PSO rate constants of Cd$^{2+}$ and Pb$^{2+}$ adsorption at 30 °C.

| Isotherm parameters               | Cd $^{2+}$ | Pb $^{2+}$ |
|-----------------------------------|------------|------------|
| **Pseudo-first-order (PFO) model**|            |            |
| Theoretical $q_e$ (mg/g)          | 40.5       | 77.65      |
| Experimental $q_e$ (mg/g)         | 42         | 78.8       |
| $K_1$ (min$^{-1}$)                | 0.075      | 0.0083     |

![Figure 9](image_url)  
Figure 9. The pseudo-second-order kinetic model fitting for the adsorption of Cd $^{2+}$ and Pb $^{2+}$ ions

Table 4. PFO and PSO rate constants of Cd$^{2+}$ and Pb$^{2+}$ adsorption at 30 °C.

| Isotherm parameters               | Cd $^{2+}$ | Pb $^{2+}$ |
|-----------------------------------|------------|------------|
| **Pseudo-second-order (PSO) model**|            |            |
| Theoretical $q_e$ (mg/g)          | 44.5       | 79         |
| Experimental $q_e$ (mg/g)         | 42         | 44.85      |
| $K_2$ (mg/g.min$^{-1}$)           | 0.0671     | 0.0079     |

4. Conclusion

Eichhornia (water hyacinth) activated carbon (EAC) offered a low-cost and effective adsorbent for removal of Cd $^{2+}$ and Pb $^{2+}$ from an aqueous solution. The removal capacity and efficiency were controlled by adsorbent dosage, agitation time, the pH of the solution, and metal ion concentration. The experimental data were found to be fitted well with the Freundlich and Langmuir isotherm models. Freundlich isotherm model exhibited a superior fitting than the Langmuir model due to the higher values of correlation coefficient ($R^2$), which means that the adsorption of metal ions (Cd $^{2+}$ and Pb $^{2+}$) occurred as multilayers on the adsorbent surface. The isotherms offered that the capacity of adsorption for Pb $^{2+}$ was found to be higher than Cd $^{2+}$. Moreover, the experimental data for Cd $^{2+}$ and Pb $^{2+}$ adsorption were fitted with the pseudo-first-order and pseudo-second-order models. Therefore, the results reveal that the adsorption of Cd $^{2+}$ and Pb $^{2+}$ pursue the pseudo-second-order kinetic model, which indicates chemical adsorption comprises electron exchange between heavy
metal ions and Eichhornia (water hyacinth) activated carbon. Finally, Eichhornia (water hyacinth) offered low-coast raw material and renewable resources for activated carbon production for waste water pollutant removal.

References

[1] F. Fu and Q. Wang, "Removal of Heavy Metal Ions from Wastewaters: A Review," Journal of environmental management, vol. 92, pp. 407-18, 03/01 2011.
[2] A. Sigdel, W. Jung, B. Min, M. Lee, U. Choi, T. Timmes, et al., "Concurrent removal of cadmium and benzene from aqueous solution by powdered activated carbon impregnated alginate beads," CATENA, vol. 148, pp. 101-107, 2017/01/01/ 2017.
[3] A. Jusoh, L. Su Shiung, N. a. Ali, and M. J. M. M. Noor, "A simulation study of the removal efficiency of granular activated carbon on cadmium and lead," Desalination, vol. 206, pp. 9-16, 2007/02/05/ 2007.
[4] K. C. Kang, S. S. Kim, J. W. Choi, and S. H. Kwon, "Sorption of Cu2+ and Cd2+ onto acid- and base-pretreated granular activated carbon and activated carbon fiber samples," Journal of Industrial and Engineering Chemistry, vol. 14, pp. 131-135, 2008/01/01/ 2008.
[5] A. Kongsuwan, P. Patnukao, and P. Pavanant, "Binary component sorption of Cu(II) and Pb(II) with activated carbon from Eucalyptus camaldulensis Dehn bark," Journal of Industrial and Engineering Chemistry, vol. 15, pp. 465-470, 2009/07/25/ 2009.
[6] M. Guo, G. Qiu, and W. Song, "Poultry litter-based activated carbon for removing heavy metal ions in water," Waste Management, vol. 30, pp. 308-315, 2010/02/01/ 2010.
[7] E. Asuquo, A. Martin, P. Nzerem, F. Siperstein, and X. Fan, "Adsorption of Cd(II) and Pb(II) ions from aqueous solutions using mesoporous activated carbon adsorbent: Equilibrium, kinetics and characterisation studies," Journal of Environmental Chemical Engineering, vol. 5, pp. 679-698, 2017/02/01/ 2017.
[8] I. A. Aguayo-Villarreal, A. Bonilla-Petriciolet, and R. Muñiz-Valencia, "Preparation of activated carbons from pecan nutshell and their application in the antagonistic adsorption of heavy metal ions," Journal of Molecular Liquids, vol. 230, pp. 686-695, 2017/03/01/ 2017.
[9] J. M. Salman, V. O. Njoku, and B. H. Hameed, "Bentazon and carbofuran adsorption onto date seed activated carbon: Kinetics and equilibrium," Chemical Engineering Journal, vol. 173, pp. 361-368, 2011/09/15/ 2011.
[10] P. González-García, S. Gamboa-González, I. Andrade Martínez, and T. Hernández-Quiroz, "Preparation of activated carbon from water hyacinth stems by chemical activation with K2CO3 and its performance as adsorbent of sodium naproxen," Environmental Progress & Sustainable Energy, vol. 39, p. e13366, 2020.
[11] J. M. Salman, V. O. Njoku, and B. H. Hameed, "Adsorption of pesticides from aqueous solution onto banana stalk activated carbon," Chemical Engineering Journal, vol. 174, pp. 41-48, 2011/10/15/ 2011.
[12] A. K. Giri, R. Patel, and S. Mandal, "Removal of Cr (VI) from aqueous solution by Eichhornia crassipes root biomass-derived activated carbon," *Chemical Engineering Journal*, vol. 185-186, pp. 71-81, 2012/03/15/ 2012.

[13] J. M. Salman, V. O. Njoku, and B. H. Hameed, "Batch and fixed-bed adsorption of 2,4-dichlorophenoxycetic acid onto oil palm frond activated carbon," *Chemical Engineering Journal*, vol. 174, pp. 33-40, 2011/10/15/ 2011.

[14] M. H. Al-Malack and A. Basaleh, *Adsorption of heavy metals using activated carbon produced from municipal organic solid waste* vol. 57, 2016.

[15] M. A. Z. Abidin, A. A. Jalil, S. Triawahono, S. H. Adam, and N. H. Nazirah Kamarudin, "Recovery of gold(III) from an aqueous solution onto a durio zibethinus husk," *Biochemical Engineering Journal*, vol. 54, pp. 124-131, 2011/04/15/ 2011.

[16] Y.-H. Li, Z. Di, J. Ding, D. Wu, Z. Luan, and Y. Zhu, "Adsorption thermodynamic, kinetic and desorption studies of Pb2+ on carbon nanotubes," *Water Research*, vol. 39, pp. 605-609, 2005/02/01/ 2005.

[17] Y. Örkün, N. Karatepe, and R. Yavuz, *Influence of Temperature and Impregnation Ratio of H3PO4 on the Production of Activated Carbon from Hazelnut Shell* vol. 121, 2012.

[18] A. A, O. Bakather, B. Tawabini, A. A. Bukhari, M. Khaled, M. Al-Harthi, et al., *Removal of Chromium (III) from Water by Using Modified and Nonmodified Carbon Nanotubes* vol. 2010, 2010.

[19] C. Gabaldón, P. Marzal, A. Seco, and J. Gonzalez, *Cadmium and Copper Removal by a Granular Activated Carbon in Laboratory Column Systems* vol. 35(7), 2000.

[20] M. Kobya, E. Demirbas, E. Senturk, and M. Ince, "Adsorption of heavy metal ions from aqueous solutions by activated carbon prepared from apricot stone," *Bioresource Technology*, vol. 96, pp. 1518-1521, 2005/09/01/ 2005.

[21] V. C. Srivastava, I. D. Mall, and I. M. Mishra, "Adsorption of toxic metal ions onto activated carbon: Study of sorption behaviour through characterization and kinetics," *Chemical Engineering and Processing: Process Intensification*, vol. 47, pp. 1269-1280, 2008/08/01/ 2008.

[22] Y. Onundi, M. A.A, M. Alkhatib, and Y. M. Ahmed, "Adsorption of Copper, Nickel and Lead Ions from Synthetic Semiconductor Industrial Wastewater by Palm Shell Activated Carbon," *International Journal of Environmental Science and Technology*, vol. 7, pp. 751-758, 09/01 2010.

[23] S. Chatterjee and S. H. Woo, "The removal of nitrate from aqueous solutions by chitosan hydrogel beads," *J Hazard Mater*, vol. 164, pp. 1012-8, May 30 2009.

[24] H. Demiral, İ. Demiral, F. Tümsek, and B. Karabacakoğlu, "Adsorption of chromium(VI) from aqueous solution by activated carbon derived from olive bagasse and applicability of different adsorption models," *Chemical Engineering Journal*, vol. 144, pp. 188-196, 2008/10/15/ 2008.

[25] S. Khaoya and U. Pancharoen, "Removal of Lead (II) from Battery Industry Wastewater by HFSLM," *International Journal of Chemical Engineering and Applications*, vol. 3, pp. 98-103, 01/01 2012.
[26] A. Adeleke, A. A. Abdul Latiff, Z. Daud, M. Ridzuan, and A. H. Jagaba, "Preparation and Characterization of Activated Cow Bone Powder for the Adsorption of Cadmium from Palm Oil Mill Effluent," *IOP Conference Series: Materials Science and Engineering*, vol. 136, p. 012045, 07/01/2016.

**Acknowledgement**
The author would like to express his gratitude to the Department of Biochemical Engineering, Al-Khwarizmi College of Engineering, University of Baghdad for technical support provided throughout the research period.