Determination of Kinetic Parameters in the Biosorption of Chromium (VI) in Aqueous Solution

Candelaria Tejada-Tovar\textsuperscript{1}, Angel Villabona-Ortíz\textsuperscript{2} and Rodrigo Ortega-Toro\textsuperscript{3}

Received: 16-08-2019 | Accepted: 13-03-2020 | Online: 19-06-2020

PACS: 68.43.-h
doi:10.17230/ingciencia.16.31.6

Abstract

The contamination of aquatic bodies by heavy metals is a growing environmental problem, making more critical the study and development of new technologies and materials that can be used for the removal of this type of pollutants. Thus, adsorption arises using residual materials as a sustainable alternative for the solution to this problem. In the present study, the use of plantain peels in the adsorption of Cr (VI) in a batch system is proposed, establishing the kinetics of the process at different temperature conditions, particle size and amount of adsorbent. The fit of the data was done using the theoretical models of pseudo-first-order, pseudo-second-order and Elovich. From the data, it is established that the pseudo-second-order and Elovich models show a better adjustment, so that the adsorption in the material occurs on two adsorption sites and that such process is related to chemical adsorption. The maximum

\textsuperscript{1} Universidad de Cartagena, ctejadat@unicartagena.edu.co, Cartagena, Colombia.
\textsuperscript{2} Universidad de Cartagena, avillabonao@unicartagena.edu.co, Cartagena, Colombia.
\textsuperscript{3} Universidad de Cartagena, rortegap1@unicartagena.edu.co, Cartagena, Colombia.
adsorption capacity of Cr (VI) was found at a condition of 0.0306 g, 0.6775 mm and 55°C at a time of 420 min establishing the efficient use of plantain peels for the removal of the ion metallic in the studio.

**Keywords:** Kinetic models; metallic ion; peels; removal; Chromium (VI)

---

**Determination of Kinetic Parameters in the Biosorption of Chromium (VI) in Aqueous Solution**

1 **Introduction**

One of the main challenges many countries around the world are facing is the decrease in the supply of safe and clean drinking water. Similarly, the presence of heavy metals in high concentrations is an environmental problem due to the adverse effects for human health, as well as for ecosystems [1]. Residues from industries such as mining, electroplating, tanneries, textiles, ceramics, photography, gravure and battery manufacturing, contain moderate to excessive amounts of...
hexavalent chromium compounds beyond the conventional legal limit of 0.1 mg/L \[2,3,4,5\].

Cr (VI) can exist in the form of dichromate \((Cr_2O_7^{2−})\), hydrochromate \((HCrO_4^{−})\) or chromate \((CrO_4^{2−})\) depending on the pH and redox potential of the medium \[6\]. The treatment of these effluents is necessary because, in humans, Cr (VI) causes lung cancer, ulcers, perforations of the nasal septum and damage to the kidneys and liver \[7\]. Various physicochemical methods are used for the removal of heavy metals from aqueous solutions such as solvent extraction \[8\], ion exchange \[9\], chemical precipitation \[10\], reverse osmosis \[11\], and membrane separation \[12\]. However, some methods require energy, chemical additives, and have a limitation against concentrations below 50 ppm \[13\]. So, the development of efficient and low-cost separation processes is, therefore, of great importance.

Accordingly, bio-adsorption is a viable alternative to achieve the desired objective, which again requires the development of new adsorbents with efficient adsorption capacities \[4\]. The use of biomass from agricultural residues as adsorbents has been widely researched, due to the low cost, immediate availability and high removal efficiency. Various bio-adsorbents such as plantain peels \[6,13\], cassava shells \[14\], orange peels \[15\], rice husk \[5\], cocoa peels \[16\], tea waste \[17\], potato husks \[1\], lemon \[18\], coffee pulp \[19\], and other husks were tested for the removal of these contaminants \[20,21\]. Therefore, in the present study, the adsorption kinetics of Cr (VI) in aqueous media were investigated using plantain peels, at different temperature conditions \(°C\), adsorbent dose \(g\) and particle size.

2 Methodology

2.1 Preparation of biomass and solution

The plantain peels came from farms in Santa Rosa and Villanueva (Colombia), being waste products in agro-industrial production processes. The plantain peels were subjected to a washing process, then, a manual size reduction was made for the subsequent stages and washed again with distilled water to remove tannins and resins. The husks were dried for 8h at 60 °C in an oven. After the drying process, the biomass was reduced
in size and classified in a shaker type sieve through a series of sieves to choose the appropriate particle size for the adsorption process. The sizes used were: 0.135, 0.355, 0.6775, 1 and 1.219 mm, as shown in the [22].

The synthetic solution of Cr (VI) was prepared using 0.2828 g of potassium dichromate ($K_2Cr_2O_7$) in 1 L of deionized water to obtain a concentration of 100 ppm of the solution, which pH was 2 [23], [24].

### 2.2 Kinetic essays

The design of experiments was carried out using Statgraphics Centurion XVI.II Software for Windows. The design used was a continuous linear factor on the response surface ($2^2$-star central compound). The essays were carried out in a batch system with a solution of 100 mL of Cr (VI) and a fixed agitation of 200 rpm, setting the initial concentration at 100ppm, varying the temperature of the adsorbent amount and particle size, according to the ranges established in Table 1 for a total of 15 experiments with a rotability factor of 1.6818. Samples were taken at different time intervals for 7 h.

| Independent variable | Units | $-\alpha$ | -1 | 0  | 1  | $+\alpha$ |
|----------------------|-------|------------|----|----|----|-----------|
| Temperature          | °C    | 30         | 40 | 55 | 70 | 80        |
| Adsorbent Dose       | g     | 0.031      | 0.15 | 0.325 | 0.5 | 0.619   |
| Particle size        | mm    | 0.135      | 0.355 | 0.6775 | 1   | 1.219   |

The final concentration measurements were made on an ultraviolet and visible spectrometer (UV/VIS) at 540 nm [25]. The data obtained were adjusted to the adsorption models through the software Origins Pro 8®.
2.3 Fit to the kinetic models

In order to determine and interpret the mechanisms in the process of adsorption of metal ions and the main parameters that govern the sorption kinetics, the kinetic data obtained empirically were adjusted to the models of pseudo-first-order, pseudo-second-order and Elovich.

The pseudo-first-order kinetic model

\[ q_t = q_e (1 - e^{(-k_1 t)}) \]  

Where \( q_e \) and \( q_t \) are the adsorption capacities at equilibrium, in a time \( t \), respectively expressed in (mmol/g), while \( k_1 \) is the pseudo-first-order constant (min\(^{-1}\)) [26].

The pseudo-second-order kinetic model

\[ q_t = \frac{t}{1/(k_2 q_e^2) + t/q_e} \]  

Where \( k_2 \) is the adsorption constant of second-order (g\(^{-1}\)min\(^{-1}\)), this constant is obtained from the graphic \( t/qt \) vs \( t \) [27].

Elovich model

\[ q_t = \frac{t}{\beta \ln(\alpha * \beta * t)} \]  

Where \( \alpha \) is the initial adsorption rate of the Elovich model (mg/g min), and \( \beta \) is the constant related to the extent of surface coverage and the activation energy in chemisorption (g/mg) [28].

3 Results and discussion

The adsorbent dose is one of the crucial parameters studied while conducting batch mode studies. The Figure [ ] show the kinetic at different conditions of biomass quantity and particle size, setting the temperature at 55°C; it was established that the highest capacity is reached using the least amount of biomass.
The adsorption of Cr (VI) was maximum at 0.03 g of adsorbent dose, and when the adsorbent dose was increased, the adsorption capacity decreased progressively. While having 0.03 g of adsorbent dose, 91.56 mg/g of adsorption was achieved, which was reduced to 17.79 mg/g for the adsorbent dose of 0.62 g. The low adsorption at higher doses may be due to the aggregation of adsorbent particles and the low driving force that leads to the adsorption process when the concentration of Cr (VI) decreases because an increasing number of adsorption sites cannot come into contact with the molecules of adsorbate [29, 30]. Additionally, the sites of unsaturated biosorbents at a fixed concentration of Cr (VI) and the aggregation of more adsorbent lead to a decrease in its total surface area [31].

The Figure 2 shows the kinetics at different conditions of biomass quantity and particle size, setting the temperature at 40°C. It was determined that all the materials reach equilibrium after 2 hours of processing.

From Figure 2 it is established that the best adsorption capacity of Cr (VI) is given when the amount of biomass is 0.15 g, achieving up to 36.4 mg/g of adsorption that was reduced to 19.7 mg/g for 0.5g of the adsorbent. As the phenomenon presented at 55°C, there is also a decrease...
in the adsorption capacity when increasing the adsorbent dose. Which may be since an increasing number of active adsorption sites cannot come into contact with a low concentration of Cr (VI) ions, thus decreasing the total surface area of the adsorbent [31],[32].

As the adsorbent dose was increased the adsorption capacity decreased, and this may be due to the decrease in the total adsorption surface area available for the Cr (VI) ion resulting from the superposition or aggregation of the adsorption sites. Which, by increasing the mass of adsorbent, the amount of contaminant adsorbed per unit mass of the adsorbent is reduced. Consequently, it causes a decrease in the $q_e$ value [6].

![Figure 2](image)

**Figure 2:** Adsorption kinetics of Cr (VI) with plantain peels at 40 °C.

The Figure 3 shows the kinetics at different conditions of biomass quantity and particle size, setting the temperature at 70°C. It was found that the particle size of the biomass does not affect the process, while the amount of biomass does.

The proportional increase in adsorption capacity with the dose of adsorbent, shown in Figure 3, is related to the increase in the total area available surface of contact, and therefore, the higher number of ion exchange sites available for the interaction with chromium ions [6],[15],[33].
Figure 3: Adsorption kinetics of Cr (VI) with plantain peels at 70 °C.

The Figure 4 presents the kinetics at different conditions of biomass quantity and particle size varying the temperature at 80 and 30°C. It was found that the initial rate of adsorption is higher than at 80°C, making it easier for this condition to reach equilibrium [34]. However, after 7 hours of the process, both conditions achieve the same adsorption capacity.

For the conditions studied in the Figure 4 and from the Table 2, the research established that the pseudo-second-order and Elovich models have better precision in predicting the experimental data in the adsorption study of Cr (VI) using plantain peel. On the other hand, from the value of the constant velocity $k_2$, it is established that the limiting step of the velocity for the removal can be attributed to the chemical adsorption where the formation of the covalent bond is due through the exchange of electrons between the metal ions and the binding sites of the adsorbent.

This effect occurred through the complexation of the ions with the functional groups available in the plantain peel [35]. Also, the initial adsorption rate ($\alpha$) is high, which implies the predominance of the adsorption of Cr (VI) when supposing adsorption in multilayers. In which each layer shows several energies of activation for chemisorption [36].
The Table 2 contains the adjustments to the kinetic models of pseudo-first-order, pseudo-second-order and Elovich in the adsorption of Cr (VI) with the plantain peels and the parameters found. The fit between the experimental results and the standard parameters applied was compared with the correlation coefficients. From the data reported in the Table 2, it can be inferred that the Elovich and pseudo-second-order models are the ones that best fit the experimental data. This fact is because the reported $R^2$ is close to the unit; in the same sense, the $q_e$ reported by the pseudo-second-order model is closer to the values obtained experimentally. The adjustment of these two models to the data indicates that the process is controlled by chemisorption or ion exchange. This phenomenon is caused by the presence of the different functional groups typical of biomasses of lignocellulosic origin [37],[38],[39].

Figure 4: Adsorption kinetics of Cr (VI) with platanin peels.
Table 2: Fit to the kinetic models of adsorption.

| Conditions                  | Pseudo-first order model | Pseudo-second orden model | Elovich Model |
|-----------------------------|--------------------------|---------------------------|---------------|
|                             | $k_1$: 0.03              | $k_2$: 1447.63            | $\alpha$: 15.511 |
| $55^\circ C$; 0.325 g; 0.6775 mm | $q_c$: 28.80             | $q_c$: 31.49              | $\beta$: 0.24 |
|                             | $R^2$: 0.96              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.05              | $k_2$: 3241.55            | $\alpha$: 1887.61 |
| $55^\circ C$; 0.325 g; 0.1351 mm | $q_c$: 30.25             | $q_c$: 31.84269           | $\beta$: 0.40 |
|                             | $R^2$: 0.99              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.01              | $k_2$: 533.49             | $\alpha$: 0.89 |
| $55^\circ C$; 0.325 g; 1.219 mm | $q_c$: 30.09             | $q_c$: 37.31              | $\beta$: 0.13 |
|                             | $R^2$: 0.97              | $R^2$: 0.98               |               |
|                             | $k_1$: 9.84E-6           | $k_2$: 8.02E17            | $\alpha$: 0.733 |
| $55^\circ C$; 0.0306 g; 0.6775 mm | $q_c$: 2025.31           | $q_c$: 38.63              | $\beta$: 0.033 |
|                             | $R^2$: 0.97              | $R^2$: 0.97               |               |
|                             | $k_1$: 0.051             | $k_2$: 524.10             | $\alpha$: 506.14 |
| $55^\circ C$; 0.6193 g; 0.6775 mm | $q_c$: 15.90             | $q_c$: 16.86              | $\beta$: 0.69 |
|                             | $R^2$: 0.99              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.04              | $k_2$: 600.44             | $\alpha$: 58.17 |
| $40^\circ C$; 0.15 g; 0.355 mm | $q_c$: 19.20             | $q_c$: 20.60              | $\beta$: 0.45 |
|                             | $R^2$: 0.98              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.02              | $k_2$: 224.99             | $\alpha$: 2.18 |
| $40^\circ C$; 0.15 g; 1 mm  | $q_c$: 17.66             | $q_c$: 19.94              | $\beta$: 0.23 |
|                             | $R^2$: 0.96              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.01              | $k_2$: 1352.70            | $\alpha$: 1.96 |
| $40^\circ C$; 0.5 g; 0.355 mm | $q_c$: 36.65             | $q_c$: 42.89              | $\beta$: 0.12 |
|                             | $R^2$: 0.94              | $R^2$: 0.96               |               |
|                             | $k_1$: 0.01              | $k_2$: 901.26             | $\alpha$: 1.44 |
| $40^\circ C$; 0.5 g; 1 mm  | $q_c$: 32.97             | $q_c$: 39.39              | $\beta$: 0.12 |
|                             | $R^2$: 0.94              | $R^2$: 0.97               |               |
|                             | $k_1$: 0.06              | $k_2$: 1361.31            | $\alpha$: 479992.19 |
| $70^\circ C$; 0.5 g; 1 mm  | $q_c$: 19.60             | $q_c$: 20.29              | $\beta$: 0.94 |
|                             | $R^2$: 0.99              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.06              | $k_2$: 1686.59            | $\alpha$: 5.28E7 |
| $70^\circ C$; 0.5 g; 0.355 mm | $q_c$: 19.91             | $q_c$: 20.53              | $\beta$: 1.17 |
|                             | $R^2$: 0.99              | $R^2$: 0.99               |               |
|                             | $k_1$: 0.01              | $k_2$: 5938.89            | $\alpha$: 3.89 |
| $70^\circ C$; 0.15 g; 0.355 mm | $q_c$: 58.51             | $q_c$: 67.67              | $\beta$: 0.079 |
|                             | $R^2$: 0.92              | $R^2$: 0.96               |               |
|                             | $k_1$: 0.02              | $k_2$: 9661.72            | $\alpha$: 13.33 |
| $70^\circ C$; 0.15 g; 1 mm  | $q_c$: 58.02             | $q_c$: 64.37              | $\beta$: 0.10 |
|                             | $R^2$: 0.93              | $R^2$: 0.98               |               |
|                             | $k_1$: 0.03              | $k_2$: 768.73             | $\alpha$: 6.05 |
| $80^\circ C$; 0.325 g; 0.6775 mm | $q_c$: 24.35             | $q_c$: 27.12              | $\beta$: 0.24 |
|                             | $R^2$: 0.92              | $R^2$: 0.96               |               |
|                             | $k_1$: 0.023             | $k_2$: 1320.01            | $\alpha$: 4.56 |
| $30^\circ C$; 0.325 g, 0.6775 mm | $q_c$: 30.58             | $q_c$: 34.42              | $\beta$: 0.17 |
|                             | $R^2$: 0.99              | $R^2$: 0.99               |               |
4 Conclusions

The effect of temperature, adsorbent dose and particle size of the Cr (VI) removal process was evaluated using plantain peel as a biosorbent on the adsorption kinetics; it was found that the adsorption of the ions is rapid in the first minutes. The research also concluded that the particle size has no significant effect on the process, at 40 and 55°C greater contaminant elimination capacity is achieved as the amount of adsorbent decreases, and at 70°C the adsorption capacity increases as the biosorbent dose is increased. Additionally, from the fit to the kinetic models, it was found that Elovich and pseudo-second-order adjust the experimental data, so the removal is attributed to the chemical interaction between the metal ions and the functional groups on the surface of the biosorbent. Finally, from the experimental results, the plantain peel can be used as an effective adsorbent for the removal of Cr (VI) from the aqueous solutions.

Acknowledgements

The authors thank to the Universidad de Cartagena (Colombia) for the support in the development of this work regarding laboratory/software use and time for their researchers.

References

[1] F. Mutongo, O. Kuipa, and P. K. Kuipa, “Removal of cr (vi) from aqueous solutions using powder of potato peelings as a low cost sorbent,” Bioinorganic chemistry and applications, vol. 2014, 2014. https://doi.org/10.1155/2014/973153

[2] A. Rosales, C. Rodríguez, and M. Ballen-Segura, “Remoción de contaminantes y crecimiento del alga scenedesmus sp. en aguas residuales de curtientos, comparación entre células libres e inmovilizadas,” Ingeniería y Ciencia, vol. 14, no. 28, pp. 11–34, 2018. https://doi.org/10.17230/ingciencia.14.28.1

[3] S. A. Sadeek, N. A. Negm, H. H. Hefni, and M. M. A. Wahab, “Metal adsorption by agricultural biosorbents: Adsorption isotherm, kinetic and biosorbents chemical structures,” International Journal of Ing.cienc., vol. 16, no. 31, pp. 129–143 enero-junio. 2020.
Determination of Kinetic Parameters in the Biosorption of Chromium (VI) in Aqueous Solution

*Biological Macromolecules*, vol. 81, pp. 400 – 409, 2015. https://doi.org/10.1016/j.ijbiomac.2015.08.031

[4] M. Akram, H. N. Bhatti, M. Iqbal, S. Noreen, and S. Sadaf, “Biocomposite efficiency for Cr(vi) adsorption: Kinetic, equilibrium and thermodynamics studies,” *Journal of Environmental Chemical Engineering*, vol. 5, no. 1, pp. 400 – 411, 2017. https://doi.org/10.1016/j.jece.2016.12.002

[5] E. Agrafioti, D. Kalderis, and E. Diamadopoulos, “Arsenic and chromium removal from water using biochars derived from rice husk, organic solid wastes and sewage sludge,” *Journal of Environmental Management*, vol. 133, pp. 309 – 314, 2014.

[6] N. K. Mondal, A. Samanta, S. Chakraborty, and W. A. Shaikh, “Enhanced chromium (vi) removal using banana peel dust: isotherms, kinetics and thermodynamics study,” *Sustainable Water Resources Management*, vol. 4, no. 3, pp. 489–497, 2018. https://doi.org/10.1007/s40899-017-0130-7

[7] S. Mishra and R. N. Bharagava, “Toxic and genotoxic effects of hexavalent chromium in environment and its bioremediation strategies,” *Journal of Environmental Science and Health, Part C*, vol. 34, no. 1, pp. 1–32, 2016, pMID: 26398402. https://doi.org/10.1080/10590501.2015.1096883

[8] J. Silva, A. Paiva, D. Soares, A. Labrincha, and F. Castro, “Solvent extraction applied to the recovery of heavy metals from galvanic sludge,” *Journal of Hazardous Materials*, vol. 120, no. 1, pp. 113 – 118, 2005. https://doi.org/10.1016/j.jhazmat.2004.12.008

[9] Z. Chen, Y. Liang, D. Jia, W. Chen, Z. Cui, and X. Wang, “Layered silicate rub-15 for efficient removal of UO 2 2+ and heavy metal ions by ion-exchange,” *Environmental Science: Nano*, vol. 4, no. 9, pp. 1851–1858, 2017. https://doi.org/10.1039/C7EN00366H

[10] A. Azimi, A. Azari, M. Rezakazemi, and M. Ansarpour, “Removal of heavy metals from industrial wastewaters: a review,” *ChemBioEng Reviews*, vol. 4, no. 1, pp. 37–59, 2017. https://doi.org/10.1002/cben.201600010

[11] S. Bolisetty, M. Peydayesh, and R. Mezzenga, “Sustainable technologies for water purification from heavy metals: review and analysis,” *Chemical Society Reviews*, vol. 48, no. 2, pp. 463–487, 2019. https://doi.org/10.1039/C8CS00493E

[12] C. F. Carolin, P. S. Kumar, A. Saravanan, G. J. Joshiba, and M. Naushad, “Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review,” *Journal of Environmental Chemical Engineering*, vol. 5, no. 3, pp. 2782 – 2799, 2017.
[13] Y. Li, J. Liu, Q. Yuan, H. Tang, F. Yu, and X. Lv, “A green adsorbent derived from banana peel for highly effective removal of heavy metal ions from water,” RSC Advances, vol. 6, no. 51, pp. 45041–45048, 2016. https://doi.org/10.1039/C6RA07460J

[14] M. Vasudevan, P. Ajithkumar, R. Singh, and N. Natarajan, “Mass transfer kinetics using two-site interface model for removal of Cr (vi) from aqueous solution with cassava peel and rubber tree bark as adsorbents,” Environmental Engineering Research, vol. 21, no. 2, pp. 152–163, 2016. https://doi.org/10.4491/eer.2015.152

[15] R. Naik, S. Ratan, and I. Singh, “Use of orange peel as an adsorbent for the removal of Cr(vi) from its aqueous solution,” Indian Journal of Chemical Technology, vol. 25, pp. 300–305, 05 2018.

[16] C. Tejada-Tovar, A. Villabona-Ortíz, Á. D. González-Delgado, C. Granados-Conde, and M. Jiménez-Villadiego, “Kinetics of mercury and nickel adsorption using chemically pretreated cocoa (Theobroma cacao) husks,” Transactions of the ASABE, vol. 62, no. 2, pp. 461–466, 2019.

[17] M. Nigam, S. Rajoriya, S. R. Singh, and P. Kumar, “Adsorption of Cr (vi) ion from tannery wastewater on tea waste: kinetics, equilibrium and thermodynamics studies,” Journal of Environmental Chemical Engineering, vol. 7, no. 3, p. 103188, 2019. https://doi.org/10.1016/j.jece.2019.103188

[18] N. M. Rane, S. V. Admane, and R. S. Sapkal, “Adsorption of hexavalent chromium from wastewater by using sweetlime and lemon peel powder by batch studies,” in Waste Management and Resource Efficiency, S. K. Ghosh, Ed. Singapore: Springer Singapore, 2019, pp. 1207–1220.

[19] D. L. Gómez Aguilar, J. P. Rodríguez Miranda, E. Muñoz, J. Andrés, P. Betancur, J. Fredy et al., “Coffee pulp: A sustainable alternative removal of Cr (vi) in wastewaters,” Processes, vol. 7, no. 7, p. 403, 2019. https://doi.org/10.3390/pr7070403

[20] I. Enniya, L. Rghioui, and A. Jourani, “Adsorption of hexavalent chromium in aqueous solution on activated carbon prepared from apple peels,” Sustainable Chemistry and Pharmacy, vol. 7, pp. 9–16, 2018. https://doi.org/10.1016/j.scp.2017.11.003

[21] M. Ahmadi, E. Kouhgardi, and B. Ramavandi, “Physico-chemical study of dew melon peel biochar for chromium attenuation from simulated and actual wastewaters,” Korean Journal of Chemical Engineering, vol. 33, no. 9, pp. 2589–2601, 2016. https://doi.org/10.1007/s11814-016-0135-1
[22] G. A. El-Din, A. Amer, G. Malsh, and M. Hussein, “Study on the use of banana peels for oil spill removal,” *Alexandria engineering journal*, vol. 57, no. 3, pp. 2061–2068, 2018. https://doi.org/10.1016/j.aej.2017.05.020

[23] J. Núñez-Zarur, C. Tejada-Tovar, A. Villabona-Ortíz, D. Acevedo, and R. Tejada-Tovar, “Thermodynamics, kinetics and equilibrium adsorption of cr (vi) and hg (ii) in aqueous solution on corn husk (zea mays),” *International Journal of ChemTech Research*, vol. 11, no. 5, pp. 265–280, 2018. http://dx.doi.org/10.20902/IJCTR.2018.110529

[24] C. Tejada-Tovar, A. Herrera-Barros, and A. Villabona-Ortíz, “Assessment of chemically modified lignocellulose waste for the adsorption of cr (vi),” *Revista Facultad de Ingeniería*, vol. 29, no. 54, pp. e10298–e10298, 2020. https://doi.org/10.19053/01211129.v29.n54.2020.10298

[25] Y. A. Neolaka, G. Supriyanto, and H. S. Kusuma, “Adsorption performance of cr (vi)-imprinted poly (4-vp-co-mma) supported on activated indonesia (ende-flores) natural zeolite structure for cr (vi) removal from aqueous solution,” *Journal of Environmental Chemical Engineering*, vol. 6, no. 2, pp. 3436–3443, 2018. https://doi.org/10.1016/j.jece.2018.04.053

[26] C. Tien and B. V. Ramarao, “On the significance and utility of the lagergren model and the pseudo second-order model of batch adsorption,” *Separation Science and Technology*, vol. 52, no. 6, pp. 975–986, 2017. https://doi.org/10.1080/01496395.2016.1274327

[27] Y.-S. Ho and G. McKay, “Pseudo-second order model for sorption processes,” *Process biochemistry*, vol. 34, no. 5, pp. 451–465, 1999. https://doi.org/10.1016/S0032-9592(98)00112-5

[28] M. Low, “Kinetics of chemisorption of gases on solids,” *Chemical Reviews*, vol. 60, no. 3, pp. 267–312, 1960.

[29] X. Song, L. Li, Z. Geng, L. Zhou, and L. Ji, “Effective and selective adsorption of as (iii) via imprinted magnetic fe3o4/htcc composite nanoparticles,” *Journal of environmental chemical engineering*, vol. 5, no. 1, pp. 16–25, 2017. https://doi.org/10.1021/cr60205a003

[30] X. Tao, Y. Wu, and L. Cha, “Shaddock peels-based activated carbon as cost-saving adsorbents for efficient removal of cr (vi) and methyl orange,” *Environmental Science and Pollution Research*, vol. 26, no. 19, pp. 19828–19842, 2019. https://doi.org/10.1007/s11356-019-05322-8

[31] E.-K. Guechi and O. Hamdaoui, “Evaluation of potato peel as a novel adsorbent for the removal of cu (ii) from aqueous solutions: equilibrium, kinetic, and thermodynamic studies,” *Desalination and*
[32] G. Adebayo, A. Mohammed, and S. Sokoya, “Biosorption of Fe (ii) and Cd (ii) ions from aqueous solution using a low cost adsorbent from orange peels,” Journal of Applied Sciences and Environmental Management, vol. 20, no. 3, pp. 702–714, 2016. https://doi.org/10.4314/jasem.v20i3.25

[33] P. Premkumar, S. Ramasamy et al., “Comparative studies on the removal of chromium (vi) from aqueous solutions using raw and modified citrus limettioides peel,” Indian Journal of Chemical Technology (IJCT), vol. 25, no. 3, pp. 255–265, 2018.

[34] X. Li, K. Wang, and Y. Peng, “Exploring the interaction of silver nanoparticles with pepsin and its adsorption isotherms and kinetics,” Chemico-biological interactions, vol. 286, pp. 52–59, 2018. https://doi.org/10.1016/j.cbi.2018.03.004

[35] D. C. Ong, S. M. B. Pingul-Ong, C.-C. Kan, and M. D. G. de Luna, “Removal of nickel ions from aqueous solutions by manganese dioxide derived from groundwater treatment sludge,” Journal of cleaner production, vol. 190, pp. 443–451, 2018. https://doi.org/10.1016/j.jclepro.2018.04.175

[36] M. O. Borna, M. Pirsaheb, M. V. Niri, R. K. Mashizie, B. Kakavandi, M. R. Zare, and A. Asadi, “Batch and column studies for the adsorption of chromium (vi) on low-cost hibiscus cannabis kenaf, a green adsorbent,” Journal of the Taiwan Institute of Chemical Engineers, vol. 68, pp. 80–89, 2016. https://doi.org/10.1016/j.jtice.2016.09.022

[37] Ş. Parlayici and E. Pehlivan, “Comparative study of Cr (vi) removal by bio-waste adsorbents: equilibrium, kinetics, and thermodynamic,” Journal of Analytical Science and Technology, vol. 10, no. 1, pp. 1–8, 2019. https://doi.org/10.1186/s40543-019-0175-3

[38] M. Manjuladevi, R. Anitha, and S. Manonmani, “Kinetic study on adsorption of Cr (vi), Ni (ii), Cd (ii) and Pb (ii) ions from aqueous solutions using activated carbon prepared from cucumis melo peel,” Applied Water Science, vol. 8, no. 1, p. 36, 2018. https://doi.org/10.1007/s13201-018-0674-1

[39] Y. Yi, J. Lv, Y. Liu, and G. Wu, “Synthesis and application of modified litchi peel for removal of hexavalent chromium from aqueous solutions,” Journal of Molecular Liquids, vol. 225, pp. 28–33, 2017. https://doi.org/10.1016/j.molliq.2016.10.140