

# Continuous flow treatment of water contaminated with Cr (VI) with *E. crassipes* and bacterial cellulose

By Uriel Fernando Carreño Sayago\*<sup>1</sup>

## ABSTRACT:

Industrial wastewater treatment is essential to mitigate the impacts these waters cause in wetlands, rivers, and lagoons. Inadequate treatment has been shown to generate significant and irreversible impacts; therefore, a "continuous flow treatment of Cr(VI)-contaminated water with *E. crassipes* and bacterial cellulose" has been investigated and implemented. These adsorbent biomasses are frequently discarded and misused, as demonstrated by the case of *Eichhornia crassipes*. This aquatic plant is abundant in wetlands contaminated with organic matter, and bacterial cellulose is industrially produced and possesses ideal heavy metal adsorption capacities. The use of mass balance mathematical models has facilitated the design of treatment systems for Cr(VI)-contaminated water that incorporate these biomasses. A water treatment system was developed that achieved a Cr(VI) removal rate greater than 99%. Furthermore, these biomasses have the ability to be filtered and therefore reused, thus increasing their functionality. Because of this, this treatment system has become a reality for the proper treatment of industrial wastewater, thanks to its high efficiency in removing metals. It is also ideal for its cost-effectiveness (costing no more than 20 euros).

*Keywords:* *E. crassipes*; Cellulose bacterial; Flow Continue; Chromium.

## 1. Introduction.

The treatment of industrial wastewater is a fundamental aspect of the conservation of aquatic ecosystems. Research related to these treatments is essential for the proper fulfilment of the Sustainable Development Goals, especially goal 6. Consequently, research has been conducted on heavy metal adsorbent biomasses. These metals have been demonstrated to have profound ramifications for the surrounding ecosystems in which they are discharged, giving rise to a plethora of detrimental impacts on the environment, society and economy (Sayago et al., 2020). This is primarily attributable to the irreversible deterioration and damage that is wrought, most notably in the instance of chromium (VI), the Cr (VI) This heavy metal is a major pollutant because it impacts areas of human importance, causing serious health consequences. It is primarily used in the leather, paint, and metalworking industries, among others. (Ramirez et al., 2022; Saade et al., 2022). Adsorbent biomasses are defined as those that possess the intrinsic capacity to chemisorb these heavy metals, thereby removing them from industrial effluents (Zhang et al., 2024; Carreño, 2020; Rohman et al., 2024; Sayago et al., 2025). The *E. crassipes* plant is one of the most extensively researched biomasses on a global scale (Priya & Selvan 2017). This aquatic plant is prevalent in wetlands, yet its biomass is currently underutilised (Sayago, 2021), as demonstrated by numerous studies (Sayago et al., 2025; Tan et al., 2008), the substance exhibits a high level of heavy metal retention. Another form of biomass that

|\*Department of Engineering and Basic Science, University Foundations University los Libertadores.

is created industrially in bioprocess laboratories is bacterial cellulose biomass. This cellulose has been shown to have exceptional capacities for removing heavy metals (Sayago et al., 2024; Mir et al., 2024). It has been established that both biomasses contain cellulose, a polysaccharide which contains functional groups, including hydroxyls (OH). These groups have been identified as the location for the binding of heavy metals (Ramirez et al., 2021; Hosseini et al., 2022; Leal et al., 2022). However, research has been conducted at laboratory scale, but pilot or industrial-scale research is required to evaluate the feasibility of creating alternative treatment systems with these biomasses. An interesting approach to conducting pilot-scale tests involves experiments with continuous flow and fixed adsorbents. This methodology allows for the evaluation of not only the effectiveness of removal, but also the contaminant load, the treated volume, and biomass densities. This approach is advantageous in that it avoids vortexes during treatment. A series of pilot-scale experiments have been conducted on *E. crassipes*, yielding removal rates of approximately 90% and a capacity of 20 mg/g (Sayago, 2021). In bacterial cellulose, the capacities are approximately three times those of *E. crassipes* biomass, with around 65 mg/g (Sayago & Ballesteros, 2023). It has been shown that when building pilot-scale prototypes with fixed biomass, a downward flow is ideal when it is funnel-shaped. This brings the biomass into direct contact with the contaminant and prevents eddy effects (Sayago & Ballesteros, 2025; Sayago, 2021). However, when considering the reuse of these biomasses, *E. crassipes* cellulose demonstrates slightly greater resistance than bacterial cellulose, and its production is more economical (Sayago et al., 2025; Yalcin et al., 2024). It is evident that a combination of these biomasses, as evidenced by these analyses, would be a very interesting proposition. Such a combination would not only verify their performance, but also their resilience in terms of reuse. Furthermore, it would enable an estimation to be made of the cost of obtaining them. Consequently, the project was initiated with the objective of "designing a continuous flow treatment of water contaminated with Cr (VI) with *E. crassipes* and bacterial cellulose, evaluating different quality parameters."

## 2. Methods and materials

### 2.1 Use of *Crassipes*

Dead *E. crassipes* plants were collected as they were being disposed of in a wetland south of Bogotá. Approximately 86 plants were collected and then air-dried for 4 days. This biomass was ground, yielding a size less than 0.211 mm.

### 2.2 Production of Bacterial Cellulose

Production took place in the laboratories of the Universidad Libertadores. Biological reactors were used to produce bacterial cellulose, containing 0.5 L of water, strawberry tea (3.3 g), sugar (1.8 g), and yeast (2.7 g). To this culture medium, 300 ml of kombucha mushroom tea liquid was added. Sampling and monitoring were carried out at constant levels, including pH, dissolved oxygen, and temperature. The plant was then dried in an oven. Cellulose films were seen growing in the bioreactors for about two weeks. Like the *E. crassipes* biomass, it was also ground to a diameter of 0.211 mm.

### 2.3 Analysed of chromium

The 1000 (mg/l) Cr (VI) stock solution was prepared with distilled water using potassium dichromate. This stock solution was used to prepare the test solutions of 300 and 600 mg/l Cr (VI), is some same to the utilized in the tannery industry (Dang et al, 2022). Twenty microliters of treated water were sampled in a KASAI MIKRO 200 centrifuge to determine the final chromium concentration, which was then transferred to a Turner SP8-15 UV-VIS spectrophotometer. All chromium sampling was performed using the American Public Health Association (APHA) standard method.

To determine chromium, the diphenylcarbazide method was used. An Eppendorf tube is used, adding 200 µl of diphenylcarbazide with 0.6% (w/v) acetone, followed by 900 µl of phosphate buffer and 100 µl of the chromium sample to be analyzed. The sample is transferred to a spectrophotometer in an adsorption cell, where it is measured at a wavelength of 540 nm.

### 2.4 Experiments conducted within a column

Two capsules or compartments were constructed to house the dried and ground biomass, with a capacity of approximately 22.5 g per compartment. The columns used in this study were 42 cm long and 4.5 cm in diameter, resulting in a volume of 1000 cm<sup>3</sup>. Each capsule was connected, thus dividing the flow in two, with openings in the lids allowing the treated water to flow to the next sampling stage. The flow rate was 20 ml/min, regulated at the inlet, ensuring this flow rate by dripping. The biomass density was kept constant, as was the temperature at 20°C and the pressure at 1 bar. An additional compartment was used for the final sampling. The tests were carried out under neutral pH conditions of the samples, which favours the adsorption process in this type of biomass and also resembles the conditions of industrial effluents (Sayago & Castro, 2022).

Chromium (VI) concentrations of 600 and 300 mg/L were evaluated. For statistical purposes, two tests were conducted per treatment, and the average of the data obtained was calculated. The development process of the pilot-scale systems is illustrated in Figure 1. Three experimental design parameters were used:

- a. Biomass (A): *E. crassipes* 75% 33.75g and bacterial cellulose 25% 11.25g
- b. Biomass (B): *E. crassipes* 50% 22.5g and bacterial cellulose 50% 22.5g
- c. Biomass (C). *E. crassipes* 25% 11.25 g and 75% bacterial cellulose 33.75

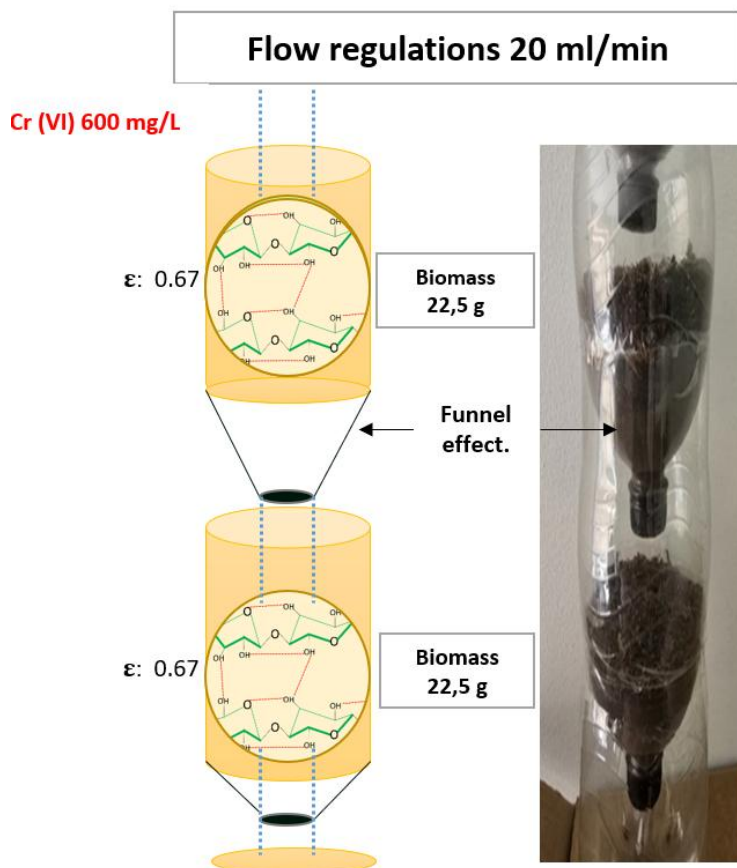


Figure 1. Design of treatment

Figure 1 shows that the capsules' distribution has a funnel-like effect at the end of the biomasses. This facilitates flow, allowing for more direct contact between the Chromium (VI)-laden solution and the biomass.

## 2.5 The process of desorption and subsequent adsorption

Subsequent to each treatment, experimental elution with EDTA was conducted, at which point the biomass had already attained a state of saturation. Elution with EDTA was performed by passing this reagent through the fixed column system, mimicking the treatment process, under a concentration of 3000 mg/L of EDTA, using 400 ml of this solution. This procedure was adapted from the methods described in the works of (Fujita et al., 2025) and (Stachurski et al., 2025).

### 2.6 Mass balance in the treatment

$$(1) \quad \varepsilon * \frac{\partial Cr}{\partial t} = \frac{\partial Cr(VI)}{\partial t} - \frac{\partial Cr}{\partial t} - \frac{M}{V} * \frac{\partial q}{\partial t}$$

Through equation (1), it would be possible to validate and calibrate modelling processes in a heavy metal adsorption system in porous media. Because parameters such as the volume to be treated  $V$  (ml); the porosity  $\varepsilon$ ; the initial concentrations of contaminants  $C_0$  (mg/L) together with the concentrations of discharge requirements  $C_f$  (mg/L); the flow rate  $Q$  (ml/min); breakthrough times  $T_b$  (min); the amount of biomass to be used  $m$  (g) and the adsorption capacity  $q$  (mg/g) could be modelled. From equation (1) the adsorption capacity is used, widely used in research processes on adsorbent biomasses. (2).

$$q = \frac{QT_b C_0}{M} - \frac{QT_b C_f}{M} - \frac{\varepsilon V C_0}{M}$$

The determination of adsorption capacity is typically accomplished through the utilisation of an equation that considers solely the initial concentrations, biomass, and the volume of the treated substance. This equation also considers the breakthrough point, densities, and flow rates (Carreño et al., 2022). Equation (1) is also adjusted in this research to calculate through equation (3) the processes of elution and reuse of biomass.

$$(3). \quad q_T = \sum_{j=1}^n \left[ \frac{QT_{bj} C_0}{M} - \frac{QT_{bj} C_f}{M} - \frac{\varepsilon V C_0}{M} \right]$$

**T<sub>bj</sub> = Breakthrough time for use number j (min)**

**q<sub>T</sub> = Total adsorption capacity of the biomass used (mg/g)**

### 3. Results

Figures 2 and 3 show the Cr (VI) removal processes by biomasses. The results of the Cr(VI) removal process by biomass were performed in duplicate. The graphs represent the average of the two data points, and the error bars represent the standardized errors

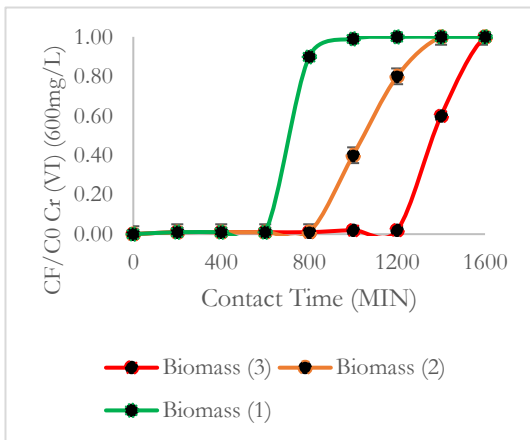


Figure 2. Initial Cr (VI) of mg/L

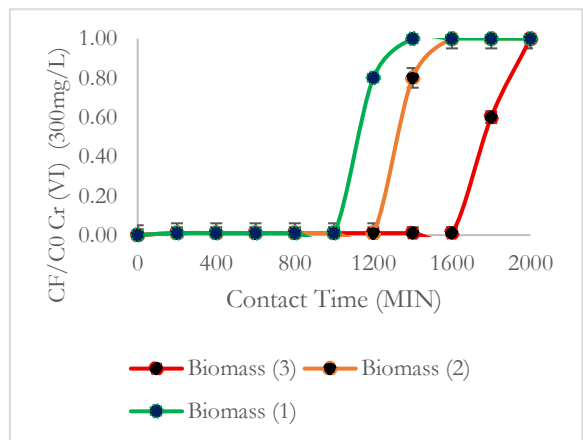


Figure 3. Initial Cr (VI) of mg/L

Biomass (1), composed predominantly of *E. crassipes* (75%), exhibited ideal removal efficiencies, but not as significant as those provided by the other two biomasses. The combination of *E. crassipes* biomass and bacterial cellulose biomass (2) was found to produce breakthrough times of 800 minutes, thus demonstrating an important combination of these biomasses. The biomass (3), which contains 75% bacterial cellulose, exhibited noteworthy removal rates, given that this biomass contains 100% cellulose (Marghaki et al., 2021; Gregory et al., 2021). The majority of cation exchange between the heavy metal and the active sites occurs in cellulose (Xiaorui et al., 2022; Lee et al., 2012). As demonstrated in the study by Sayago et al. (2024), the plant biomass of *E. crassipes* contains significant quantities of lignin, hemicellulose and cellulose. The proportion of cellulose and hemicellulose is approximately 66%, which hinders the plant's capacity for effective heavy metal removal.

### 3.1 Adsorption Capacities

Using equation (2), the adsorption capacities of each biomass were determined, using the highest concentration of 600 mg/L. Biomass (1) was used as an example, with a breakpoint determined at around 600 minutes.

$$q(\text{biomass 1}) = \frac{600 \cdot 15 \cdot 0.6}{45} - \frac{600 \cdot 15 \cdot 0.06}{45} - \frac{0.66 \cdot 68 \cdot 0.6}{45}$$

Co: 0.6 mg/ml; Cf: 0.06 mg/ml; M: 45 g; Tb: Breakthrough time 600 min; Q: Flow rate 15 ml/min; ε: 0.66 (Worc 2012); V: Occupied volume: 68 ml

Table 1 shows the adsorption capacities and breakthrough curves.

**Table 1:** summary of the parameters

Experiment	Biomass	Biomass	Biomass
600 mg/L	(1)	(2)	(3)
Volume treat (ml)	1400	1600	1800
Tb (min)	600	800	1200
<b>q (mg/g)</b>	<b>107</b>	<b>121</b>	<b>136</b>

It can be seen that the biomass (3) has an adsorption capacity of 136 mg/g, in which the amount of bacterial cellulose was reflected in this capacity, treating around 800 ml of contaminated water with an initial chromium (VI) of 600 mg/L. The biomass (2), which has a capacity of 121 mg/g together with 1600 ml of treated water and the biomass (1), has a lower adsorption capacity but with an appreciable amount of *E. crassipes*, this biomass being less expensive. These biomasses have been adapted to remove other heavy metals, for example, *E. crassipes* biomass has an adsorption capacity of 15 mg/g for As (Lin et al, 2012) and 35 mg/g for Pb (Zhou et al, 2020). Bacterial cellulose biomass has an adsorption capacity of 100 mg/g for As (Motloun et al., 2023) and 120 mg/g for Pb (Kaur et al, 2022).

### 3.2 Elution

The capacity of the second elution with EDTA was established using equation (3). The second elution for biomass (1) yielded the following results:

$$q(\text{biomass 1}) = \frac{500 \cdot 15 \cdot 0.6}{45} - \frac{500 \cdot 15 \cdot 0.06}{45} - \frac{0.66 \cdot 68 \cdot 0.6}{45} =$$

Co: 0.6 mg/ml; CF: 0.06 mg/ml; M: 45 g Tb 500 min; Q: 15 ml/min; e: 0.66 (Worc 2012).

The initial biomass capacity (1) was 107 mg/g, and following elution in the second treatment process, the capacity was reduced to 88 mg/g. Despite the lower level of process capacity, it was nevertheless considerable. The breakthrough time was approximately 500 minutes, allowing for the treatment of approximately 1125 millilitres, which is 275 millilitres less than with the fresh biomass. The third process was also significant, providing a capacity of 60 mg/g, while the fourth elution process provided a capacity of 45 mg/g. The terms under discussion are translated into equation (4).

$$q_T = 107 + 88 + 60 + 45 + 25 = 325 \text{ mg/g}$$

As illustrated in Figure 4, the diverse elution processes of the biomasses and composite materials analysed are evident.

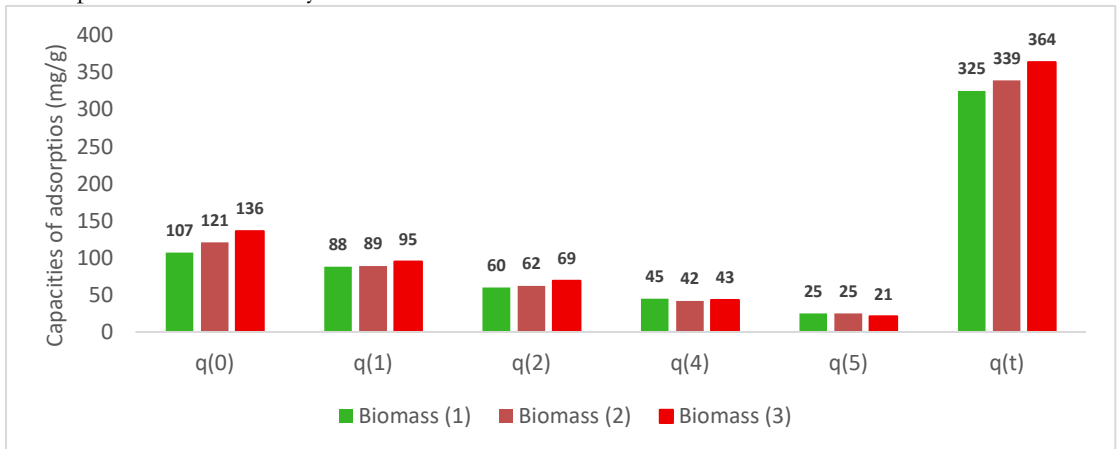


Figure. 4 Adsorption capacities in the different adsorption processes.

The capacity of 325 mg/g (Biomass, 1), this biomass under scrutiny contains a significant proportion of *E. crassipes*, and its elevated lignin content renders the elution process more robust in comparison to other biomasses (Sayago, 2021). It was established that the biomass (2) obtained possessed a total adsorption capacity of 339 mg/g. The composite of these biomasses renders this composite material ideal for treatment, combining the resistance of *E. crassipes* with the excellent adsorption capacities of bacterial cellulose. It was established that the best totals were obtained by biomass (3), with bacterial cellulose being identified as a promising biomass for the removal of heavy metals, especially Cr(VI).

### 3.3 Treatment system costs.

The cost of drying, grinding, and logistics for obtaining *E. crassipes* is approximately \$2 per kilogram of biomass (Sayago et al., 2021). The financial outlay required for the production of bacterial cellulose is approximately \$15, taking into account the cost of the Kombucha mushroom, which is approximately \$8 per 600 ml, and adding yeast and red tea would yield a total of \$20 (Sayago et al., 2021). EDTA is priced at \$0.20 per elution (Fujita et al., 2025). As illustrated in Table 2, the associated costs are presented alongside the previously established capacities and their respective relationships. It is evident that biomass (3), which contains a higher amount of bacterial cellulose (75%), is more expensive than the other two biomasses. The cost of biomass (3) is \$20, which includes the production of bacterial cellulose and the logistics of obtaining the *E. crassipes* biomass. The cost of biomass (2) is approximately \$14, and the cost of biomass (3) is \$12.

**Table 2:** Costs associated with treatment systems.

Costs	Biomass		Biomass	
	(1)	(2)	Biomass (2)	Biomass (3)
qt (g Cr /kg biomass)		325	339	364
Cost 1 Kg biomass		12	15	22
<hr/>				
g Cr / (USD)		27.08	22.6	16.54

Table 2 shows the relationship between the sums of adsorption capacities combined with the costs of obtaining the material, obtaining an interesting parameter of grams of Chromium treated per dollar used in the process, due to the low costs of obtaining for *E. crassipes*, the biomass (1) obtained a better performance in this effectiveness parameter.

### Conclusions

The objective of this study was to design a sustainable and economical Cr(VI) treatment system. The system was designed with *E. crassipes* and bacterial cellulose adsorbent biomasses. The system setup comprises the integration of a pilot system that emulates a treatment process in the tanning industry. This system comprises three experiments, with favourable results for its industrial scaling. Under circumstances of excessive load, the implementation of a biomass (1) treatment system has proven to be an effective solution, due to the bacterial cellulose's superior performance in the removal of heavy metals. Furthermore, when considerable flow rates are present, the implementation of biomass (2) treatment systems has proven to be advantageous, due to the optimal mixing of these two adsorbent biomasses. In scenarios with financial constraints, the design and implementation of a biomass (3) system has proven to be a cost-effective alternative, thanks to its high efficiency and low operating costs. One of the potential limitations is the availability of materials, as well as the appropriate adaptation depending on the effluent and the responsibility of the business owners who own their chromium-laden effluents. This treatment system is characterized by its high level of sustainability

and minimal impact on the environment. This treatment system, based on these biomasses, is already available for use in industries that contaminate with Cr (VI). The cost-effectiveness of the system, its versatility in different treatment cycles, and its ease of access all contribute to its potential for large-scale implementation. This contributes to the improvement of water quality and, consequently, to achieving objective number 6 of the Sustainable Development Goals.

**Acknowledgment:** The article was written as part of the project “biomass adsorbents”, funded by the Fundación Universitaria los Libertadores. Colombia

## References.

- Carreno Sayago, U. F. (2021). Design, scaling, and development of biofilters with e crassipes for treatment of water contaminated with Cr (VI). *Water*, 13(9), 1317.
- Dang, X., Yu, Z., Yang, M., Woo, M. W., Song, Y., Wang, X., & Zhang, H. (2022). Sustainable electrochemical synthesis of natural starch-based biomass adsorbent with ultrahigh adsorption capacity for Cr (VI) and dyes removal. *Separation and Purification Technology*, 288, 120668.
- Fujita, S., Sasa, R., Kinoshita, N., Kishimoto, R., & Kono, H. (2025). Nano-Fibrillated Bacterial Cellulose Nanofiber Surface Modification with EDTA for the Effective Removal of Heavy Metal Ions in Aqueous Solutions. *Materials*, 18(2), 374.
- Gaballah, M. S., Ismail, K., Aboagye, D., Ismail, M. M., Sobhi, M., & Stefanakis, A. I. (2021). Effect of design and operational parameters on nutrients and heavy metal removal in pilot floating treatment wetlands with Eichhornia Crassipes treating polluted lake water. *Environmental Science and Pollution Research*, 28, 25664-25678.
- Gregory, D. A., Tripathi, L., Fricker, A. T., Asare, E., Orlando, I., Raghavendran, V., & Roy, I. (2021). Bacterial cellulose: A smart biomaterial with diverse applications. *Materials Science and Engineering: R: Reports*, 145, 100623.
- Hosseini Talari, M., Tabrizi, N. S., Babaeipour, V., & Halek, F. (2022). Adsorptive removal of organic pollutants from water by carbon fiber aerogel derived from bacterial cellulose. *Journal of Sol-Gel Science and Technology*, 1-11.
- Kaur, J., Sengupta, P., & Mukhopadhyay, S. (2022). Critical review of bioadsorption on modified cellulose and removal of divalent heavy metals (Cd, Pb, and Cu). *Industrial & Engineering Chemistry Research*, 61(5), 1921-1954.
- Leal, A. N. R., de Lima, A. D. C. A., dos Anjos Azevedo, M. G. F., do Nascimento Santos, D. K. D., Zaidan, L. E. M. C., de Lima, V. F., & Cruz Filho, I. J. (2021). Removal of Remazol Black B dye using bacterial cellulose as an adsorbent. *Scientia Plena*, 17(3).
- Lee, K. Y., Tammelin, T., Schultfer, K., Kiskinen, H., Samela, J., & Bismarck, A. (2012). High performance cellulose nanocomposites: comparing the reinforcing ability of bacterial cellulose and nanofibrillated cellulose. *ACS applied materials & interfaces*, 4(8), 4078-4086.
- Lin, S., Wang, G., Na, Z., Lu, D., & Liu, Z. (2012). Long-root Eichhornia crassipes as a biodegradable adsorbent for aqueous As (III) and As (V). *Chemical Engineering Journal*, 183, 365-371.
- Marghaki, N. S., Jonoush, Z. A., & Rezaee, A. (2022). Chromium (VI) removal using microbial cellulose/nano-Fe<sub>3</sub>O<sub>4</sub>@ polypyrrole: Isotherm, kinetic and thermodynamic studies. *Materials Chemistry and Physics*, 278, 125696.
- Mir, I. S., Riaz, A., Roy, J. S., Fréchet, J., Morency, S., Gomes, O. P., ... & Messaddeq, Y. (2024). Removal of cadmium and chromium heavy metals from aqueous medium using composite bacterial cellulose membrane. *Chemical Engineering Journal*, 490, 151665.
- Motloun, M. T., Magagula, S. I., Kaleni, A., Sikhosana, T. S., Lebelo, K., & Mochane, M. J. (2023). Recent advances on chemically functionalized cellulose-based materials for arsenic removal in wastewater: a review. *Water*, 15(4), 793.

- Priya, E. S., & Selvan, P. S. (2017). Water hyacinth (*Eichhornia crassipes*)—An efficient and economic adsorbent for textile effluent treatment—A review. *Arabian Journal of Chemistry*, 10, S3548-S3558.
- Ramírez-Canon, A., Becerra-Quiroz, A. P., & Herrera-Jacquelin, F. Perfluoroalkyl and polyfluoroalkyl substances (PFAS): First survey in water samples from the Bogotá River, Colombia. *Environmental Advances*. 2022, 8, 100223.
- Ramirez-Muñoz, A., Pérez, S., Muñoz-Saldaña, J., Flórez, E., & Acelas, N. (2021). Eco-friendly materials obtained through a simple thermal transformation of water hyacinth (*Eichhornia Crassipes*) for the removal and immobilization of Cd<sup>2+</sup> and Cu<sup>2+</sup> from aqueous solutions. *Environmental Nanotechnology, Monitoring & Management*, 16, 100574.
- Rohman, G. A. N., Aziz, M. A., Nawaz, A., Elgzoly, M. A., Hossain, M. M., & Razzak, S. A. (2024). High-performance biochar from *Chlorella pyrenoidosa* algal biomass for heavy metals removal in wastewater. *Separation and Purification Technology*, 341, 126870.
- Saade-Cleves, N., Talero-Munoz, M. D. M., García-Vargas, D., Tamayo-Torres, C. S., Sierra-Pena, J. A., Torres-Ortiz, M. P., & Palencia-Sánchez, F. The Risk Index Used to Assess the Risk of Heavy Metals, Mainly in Water Sediments, on Human Health in Latin America: A Rapid Review of Literature. *Mainly in Water Sediments, on Human Health in Latin America: A Rapid Review of Literature* (December 27, 2022).
- Sarkar, M., Rahman, A. K. M. L., & Bhoumik, N. C. (2017). Remediation of chromium and copper on water hyacinth (*E. crassipes*) shoot powder. *Water resources and industry*, 17, 1-6.
- Sayago, U. F. C. (2021). Design and development of a biotreatment of *E. crassipes* for the decontamination of water with Chromium (VI). *Scientific Reports*. 11(1), 9326.
- Sayago, U. F. C., & Castro, Y. P. (2022). Development of a composite material between bacterial cellulose and *E. crassipes*, for the treatment of water contaminated by chromium (VI). *International Journal of Environmental Science and Technology*, 19(7), 6285-6298.
- Sayago, U. F. C., & Ballesteros Ballesteros, V. (2023). Recent advances in the treatment of industrial wastewater from different celluloses in continuous systems. *Polymers*, 15(19), 3996.
- Sayago, U. F. C., & Ballesteros Ballesteros, V. Development of a treatment for water contaminated with Cr (VI) using cellulose xanthogenate from *E. crassipes* on a pilot scale. *Scientific Reports*, 2023 13(1), 1970.
- Sayago, U. F. C., Ballesteros, V. B., & Aguilar, A. M. L. (2024). Designing, Modeling and Developing Scale Models for the Treatment of Water Contaminated with Cr (VI) through Bacterial Cellulose Biomass. *Water*, 16(17), 2524.
- Sayago, U. F. C., Ballesteros, V. B., & Lozano, A. M. (2025). Design of Biomass Adsorbents Based on Bacterial Cellulose and *E. crassipes* for the Removal of Cr (VI). *Polymers*, 17(12), 1712.
- Sayago, U. F. C., Ballesteros, V. B., & Lozano, A. M. (2025). Development of a Treatment System of Water with Cr (VI) Through Models Using *E. crassipes* Biomass with Iron Chloride. *Toxics*, 13(3), 230.
- Sayago, U. F. C., Castro, Y. P., Rivera, L. R. C., & Mariaca, A. G. (2020). Estimation of equilibrium times and maximum capacity of adsorption of heavy metals by *E. crassipes*. *Environmental Monitoring and Assessment*, 192, 1-16.
- Shao, Y., Fan, Z., Zhong, M., Xu, W., He, C., & Zhang, Z. (2021). Polypyrrole/bacterial cellulose nanofiber composites for hexavalent chromium removal. *Cellulose*, 28, 2229-2240.
- Stachurski, C. D., Larm, N. E., Gulbrandson, A. J., Trulove, P. C., & Durkin, D. P. (2024). Fiber welded EDTA-modified cellulose for remediation of heavy metal ions. *Carbohydrate Polymer Technologies and Applications*, 7, 100504.
- Tan, L., Zhu, D., Zhou, W., Mi, W., Ma, L., & He, W. (2008). Preferring cellulose of *Eichhornia crassipes* to prepare xanthogenate to other plant materials and its adsorption properties on copper. *Bioresource technology*, 99(10), 4460-4466.
- Worch, E. (2012). Adsorption technology in water treatment: fundamentals, processes, and modeling. *Walter de Gruyter*.
- Xiaorui, K., Cong, Z., Pin, X., Zhanwen, D., & Zhijiang, C. (2022). Copper ion-imprinted bacterial cellulose for selectively removing heavy metal ions from aqueous solution. *Cellulose*, 29(7), 4001-4019.
- Yalcin, I. E., Altay, V., & Ozturk, M. (2025). Phytoremediation potential and ecophysiological features of water hyacinth *Eichhornia crassipes*: a case study from Orontes River, Türkiye. *Journal of Environmental Science and Health, Part A*, 60(2), 66-78.

- Zhou, J. M., Jiang, Z. C., Qin, X. Q., Zhang, L. K., Huang, Q. B., & Xu, G. L. (2020). Effects and mechanisms of calcium ion addition on lead removal from water by *Eichhornia crassipes*. *International Journal of Environmental Research and Public Health*, 17(3), 928.
- Zhang, B., Ren, G., Ran, L., Liu, M., Geng, P., & Yi, W. (2024). Green synthesis of biomass-derived porous carbon for electrochemical detection of heavy metal ions: Methods, properties, and applications. *Journal of Environmental Chemical Engineering*, 113903.