Development of a research project in the pandemic - COVID 19: theoretical evaluation of the biosorption of toxic metal ions in inactive biomass, using laboratory residues containing Cr6+ and banana peel powder

Letícia Lisovski

Carolina Borges Feijó

Eliza Vargas Medina

Juliano Pacheco Paixão

Nara Regina Atz

Regina Felisberto

ABSTRACT
The pandemic (COVID-19) resulted in an impediment to carrying out face-to-face activities that were suspended, hampering the development and completion of research that requires experimental procedures. This situation raised the need to find alternatives to overcome this obstacle. For this, it was considered that the acquisition of knowledge through problem-solving strengthens teaching-learning and the student-teacher relationship and is a pedagogical resource in line with the guiding principles for Professional and Technological Education established in the National Curriculum Guidelines, (BRAZIL, 2012; 20121), and with the disciplines of Projects in the technical course in chemistry at IFRS - Campus Porto Alegre/RS. In this context, the students, authors of this article, continued work started before the pandemic, and developed, guided by teachers, this theoretical-practical project that used silver banana peel powder (PCBP) as inactive adsorbent biomass to remove ions Cr6+ from liquid waste which comes from analytical chemistry courses. The use of the peels of this fruit is relevant considering that in 2019 Brazil produced 6.8 million tons of bananas (EMBRAPA, 2019). The banana peels were dried, pulverized, and sieved. Its characterization by IR-spectrophotometry showed proper functional groups for the adsorption process. Dilutions of the laboratory liquid residue containing Cr6+, as well as the adsorption process were also performed. At this point, due to the pandemic (COVID-19), experimental activities were suspended, and analytical tests could not be performed. However, as an alternative, using results published in similar works and theoretical bases obtained in the literature, hypothetical isotherms were constructed, class C and class L that allowed inferences about the potential for biosorption of the metal ion (Cr6+) in the biomass used. This theoretical study presented the potential for new theoretical-practical studies involving other toxic metal ions and different biomass.

Keywords: Pandemic moment. Biosorption. Chrome. Isotherms adsorption.

1 INTRODUCTION

In recent years, high schools and technical schools, higher education institutions and research institutes have shown concern about the treatment and disposal ofchemical waste generated in teaching and research activities. In chemistry laboratories, for example, the waste generated is heterogeneous in relation to composition, toxicity and quantity. Often, they are disposed of improperly, rightly inthe laboratory sink, and consequently in the domestic sewage.

Industrial waste is also considered potential aggressors of the environment and living beings, being associated with pollution and toxicity. Many industries, in addition to not properly processing the waste generated in their processes, discard them without prior treatment, polluting rivers, soils, groundwater and the atmosphere.

Thus, concern arises with environmental and health issues, since possible water pollution and the consumption of fish and other contaminated foods can affect the health of living beings and the environment as a whole. Environmental pollution derived from waste from chemical laboratories or contaminated industrial effluents has aggravatedthe situation of ecosystems. Both regions close to industries, as well as the most remote localities, are subject to contamination due to the movement of bodies of water, soil and air.

Laboratory and industrial residues may contain heavy metal ionand among the possible contaminants is the hexavalent chromium metal ion (Cr^{6+}). This can cause acute toxic effects on humans and changes in genetic material that lead to the development of cancer, for example. According toWHO (World Health Organization), Cr 6+ ion has cumulative power in the body and, in addition, can cause the oxidation of biologically important compounds, such as enzymes, vitamins and cellular structures, thus causing serious transtornthem in human metabolism (ATSDR, 2012). The deficiency of trivalent chromium metal ion (Cr^{3+}) in the human body causes disorders in metabolism, glucose intolerance and diabetes. On the other hand, its excess can cause dermatitis and hepathic problems (CARMO, 2013, p.14). Chromium compounds are still often used in laboratory and industrial processes and, therefore, there is a great demand and need to minimize environmental damage caused by the treatment and inadequate disposal of liquid or solid waste stemming fromthese processes (ABNT, 2004; CETESB, 2017).

In this context, given the relevance of the problem, this project was conceived that proposes a method for evaluating the process of removal of Cr^{6+} ions from liquid residues from the teaching laboratory, using banana peel powder as inactive biomass. To perform this, laboratory liquid residues from practical analytical chemistry classes from the Technical Course in Chemistry of IFRS/*Campus* Porto Ale gre wereused. This proposal was based on a study carried out previously by students of this course, using banana peel as biomass for adsorption of cr 3+ metal ions according to DIAS *et al*, 2019, and also on the methodology developed in the studies by BONIOLO, 2008, for uranium biosorption also in banana peels.

Silver banana peel powder (PCBP) was obtained by grinding, drying and sieving of peels of this fruit. For the superficial characterization of the adsorbent (PCBP), the identification of functional groupswas performed by the infrared spectroscopy (IR) technique.

For the evaluation of the process of removal/adsorption of Cr^{6+} ions, the construction of adsorption isotherms, mathematical models that provide information on the equilibrium relationship established between the amount of the pollutant species (Cr^{6+} ions) adsorbed and its concentration in the solution, at a certain temperature, was proposed. These graphic representations can be presented in various ways. According to GILES *et al*, (1974, *apud* FRANGUELLI, 2018), depending on the curves obtained (isotherms), it is possible to understand important aspects about the removal/adsorption that occurs. The performance of this stage required experimental procedures that were not performed due to the PANDEMIC of THEID-19, and the consequent suspension of face-to-face activities in the Federal Institutes, since March 2020. Alternatively, analytical data obtained in work previously performed by DIAS *et al,* 2019, which used the same type of residue containing Cr 6+ ions were[used] as a starting point. This resource allowed the inference of values for the

initial and adsorbed chromium contents, as well as the realization of a theoretical study, which resulted in the construction of two hypotetic isotherms, class C and class L, classes that can be obtained for this type of study. The procedure demonstrated the potential to conduct theoretical and practical studies involving other toxic metals and different biomasses.

1.2 ADSORPTION ISOTERMAS

The adsorptive process employing biomass is a phenomenon that can be studied by means of adsorption isotherms. These are graphic representations that relate the amount of the ion adsorbed to the solid phase (adsorbent) with its concentration in the solution, after contact with the adsorbent, when the chemical balance is reached, at a constant temperature. There are several models of adsorption isotherms used in the description of adsorptive mechanisms related to different types of pollutants and adsorbent materials. GILES *et al* (1974, *apud* FRANGUELLI, 2018) classified adsorption isotherms into four main classes: class C isotherms ("Constant *partition*"), class L ("*Langmuir*"), class H ("*High affinity*") and class S ("*Spherical*"), as illustratedin Figure 1.

Figure 1. Main classes of isotherms. a) Class C: constant partition of the solute between the solution and the adsorbent; b) Class L: high affinity of adsorbate by adsorbent; c) Class H: special case of class L. High affinity of adsorbate by adsorbent, mainly at low concentrations; d) Class S: low affinity of adsorbate by adsorbent at low concentrations.
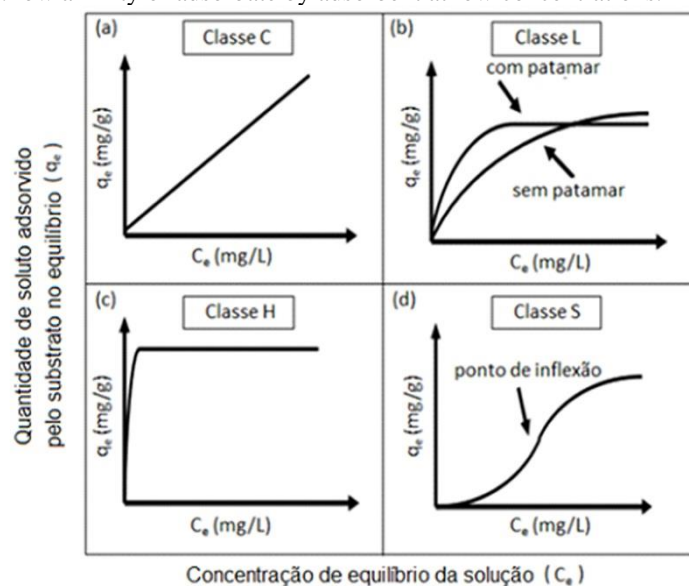
Adapted from GILES *et al*, (1974, *apud* FRANGUELLI, 2018).

The isotherm of class C (Figure 1a) is equivalent to a constant partition of the solute between the solution and the adsorbent, giving the curve a linear aspect. In this type of isotherm, the amount of active sites in the adsorbent material is constant. According to BONIOLO (2008, p. 38) "The conditions that favor type C curves are flexible porous substrates and regions of different degrees of solubility for the solute". The isotherm of class L (Figure 1b) has a nonlinear and concave inclination in relation to the abscissaand may present a level that indicates a possible saturation of the adsorbent material. According to GILES *et al* (1974, *apud* FRANGUELLI, 2018) "[...]. In case a noticeable saturation is not reached, there is a gradual reduction in the

inclination of the curve to the measurementof which the liquid interface becomes more concentrated". This fact indicates high affinity of adsorbate by adsorbent, which decreases as adsorption sites are filled. In class H isotherm (Figure 1c) it is observed that adsorbate presents alta affinity for adsorbent, mainly at low concentrations. In this case there is a high initial adsorption, and the balance is reached soon after (FRANGUELLI, 2018). The isotherm of class S (Figure 1d) has a linear and convex inclination in relation to the abscissa and describes that, at low concentrations, there is low affinity between the ions or molecules that constitute adsorbate and adsorbent (MEURER, 2006; BONIOLO, 2008). Adsorbate molecules when they are at lower concentrations in the solution compete for the active sites of the adsorbent, with other molecules present in the solution itself or with other molecules that have already been adsorbed (MEURER, 2006). Still, and according to GILES *et al* (1974, *apud* FRANGUELLI, 2018) "[...]. The xon infle point ofisotherm [Class S] consists of a cooperative adsorption [...]" that occurs when the interaction between adsorbate-adsorbate is greater than the adsorbate-adsorbent interaction.

The amount of adsorbate per unit of mass of the adorbent material (q_e) in mg.g-1 is calculated according to Equation 1, adapted from SANTOS, 2015, which is the mathematical representation of the amount of adsorbate per unit of adsorbent mass.

$$q_e = \frac{C_0 - C_e}{m} \times V$$
Equation1

Where

C_0: Initial concentration of adso hit in the solution, (mg. L-1);
          r

C_e: Final concentration of adsorbate in solution or concentration in balance, (mg. L-1);

m: Mass of adsorbent material, (g);

V: Solution volume , (L).

In this study, it was proposed the construction of two hypothetical isotherms, one class C and another class L, which are used to describe adsorptive processes of pollutants present in water and effluents, as reported in studies by ISA *et al,* 2018. Thus, without ruling out the possibility of obtaining isotherms from other classes for similar studies, it was intended to demonstrate the feasibility of using this resource and how the data obtained can be used.

Class C isotherms are linear and have parameters that can be directly evaluated. Already class L isotherms are best interpreted when linearized by the use of Equation 2, adapted from FRANGUELLI, 2018.

$$\frac{C_e}{q_e} = \frac{1}{b}Ce + \frac{1}{K.b}$$ Equation 2

Where

q_e: Amount of the ion adsorbed per unit of mass of the adsorbent material in equilibrium, (mg.g-1);

C_{and}: Ion concentration in the equilibrium solution with the solid phase, (mg. L-1);

K: Constant related to the energy of binding the ion to the surface of the substrate, ([L.mg-1]);

b: Maximum capacity of adsorption of the ion by adsorbent, (mg.g-1).

It is observed that equation 2 corresponds to the equation of a line, *type y = mx + n*, which can be graphically represented as C_{and}/q_{and} versus C_e. In this case, C_{and}/q_e represents the dependent variable (*y*); C_{and} represents the independent variable (*x*); *1/b* represents the angular coefficient (*m*) and, *1/K.b*, the linear coefficient (*n*). In this linearized equation, the parameters of maximum adsorption capacity (*b*) and adsorption energy (*K*) (FRANGUELLI, 2018) are determined by the angular and linear coefficients of the line.

2 EXPERIMENTAL PART

2.1 PREPARATION AND CHARACTERIZATION OF BIOMASS (PCBP)

The silver banana peels used as inactive biomass were cut into small pieces and dried in a greenhouse, at a temperature of 40ºC, for a period of 48 h. After drying, they were stored in a desiccator until it reached room temperature, to avoid moisture absorption. With the aid of a laboratory multiprocessor, it was grinding and the powder obtained was submitted to a sieve system, and the passing fractions were separated for this work at 150 and 200 Mesh. These twofractions were used as biomass called Silver Banana Peel Powder (PCBP), whose preparation steps are presented in Figure 2.

Figure 2. Steps used in biomass preparation (PCBP). (a) chopped silver banana peels; (b) Banan peelsthe silver dried in greenhouse at 40ºC; (c) silver banana peels, already dried, stored in desiccator; (d) Silver banana peels to be ground; (e) Silver banana peels after grinding in processor and (f) biomass (PCBP) already prepared.
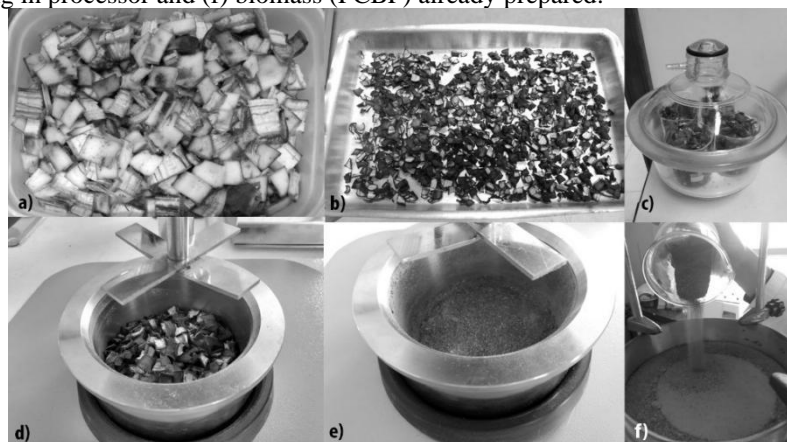
Source: elaborated by the authors (2019).

The PCBP was analyzed in an Infrared Spectrophotometer (IR), perkin Elmer Frontier, using the Total Attenuated Reflectance (ATR) technique. This method allowed the identification of the functional groups present in the biomessa studied.

2.2 PREPARATION OF LIQUID WASTE SAMPLE CONTAINING IONS Cr^{6+}

The sample of liquid residue containing Cr^{6+} ions originated from analytical chemistry classes, more precisely, from chloride ion determination (Cl^-) that employs the argentimetric method called Mohr Method. The same consists of titration of solutions containing Cl-ions, with a standard solution of silver nitrato ($AgNO_3$) in the presence of potassium chromate (K_2CrO_4), used as an indicator solution. The Mohr method is based on fractional precipitation that occurs by difference of the product of solubility (Kps) of the formed sais, silver chloride (AgCl) and silver chromate (Ag_2CrO_4). AgCl precipitation occurs first, as this silver salt is five times less soluble than Ag_2CrO_4 (AgCl solubility: 1.35 x 10-5 mol. L-1; solubility Ag_2CrO_4: 6.69 x 10-5 mol. L-1). After precipitation of allCl- ions present in the solution, the chromate ion (CrO_4^{2-}), of the indicator solution, begins to precipitate as Ag_2CrO_4. This has red coloration, defining the end point of the titration, in the region of the equivalence point. However, the $CrO_4^{ion\ 2-}$, is employedand m excess so that this still remains in solution without reacting with silver, which generates a liquid residue containing Cr 6+ ions. This residue was filtered using medium filtration paper (Whatmann/40 brand) for separation of precipitates AgCl and Ag_2CrO_4. The filtered residual solution was stored in a 5 L gallon, properly sanitized, identified as sample A.

2.3 THEORETICAL INFERENCES FOR CONCENTRATIONS OF IONS Cr^{6+}

The determination of the total chromium concentration of the liquidresidue sample originating from analytical chemistry classes (item 2.2) should be performed using the Atomic Absorption Spectrometric (EAA) technique. This experiment was not performed due to the suspension of laboratory activities by the pandemic (COVID-19).

The evaluation of the amount of Cr6+ ions adsorbed per unit of mass of the adsorbent material (PCBP), in the equilibrium, as well as its percentage of removal, would be made by isotherms to be constructed with experimentally obtained data. It wouldalso be verified the influence of PCBP granulometry (150 and 200 Mesh) on the removal of Cr 6+ ions. However, given the impossibility of performing the programmed analyses, a theoretical study was proposed to end this project and as astimulus to the students involved in it.

Thus, it was taken as a starting point for the development of the theoretical work, an analytical result previously obtained by students of this Course for the same type of residue, which corresponded to the concentration of 40 mg. L-1 d and Cr 6+ ions (DIAS et al). This inference was possible because the Mohr Method is used every six months in the practices carried out in this Course, being the residue of the same, which contains Cr6+ ions (toxic), always stored, for subsequent referral to the waste treatment plant. This residual solution, to be used as a sample in this study, was filtered and called sample A. This sample was submitted to four differentdilutions with different concentrations of Cr 6+ ions.

The concentrations of Cr^{6+} **ions of** the four solutions obtained after dilutions were 32, 28, 24 and 20 mg. L-1, called samples B, C, D and E, respectively. These samples, together with sample A, were then submitted **to** the adsorption process in the PCBP in two particle sizes: 150 and 200 Mesh.

In the impossibility of finishing the experimental work to evaluate the biosorption of Cr^{6+} ions in inactive biomass (PCBP), the removal of around 60% (m/v) of this ion was considered. This adsorption value was used based on studies by DIAS *et al,* 2019 and MARTINS, 2021 that also used banana peel as inactive biomass in adsorptive processes.

2.4 ION ADSORPTION PROCEDURE Cr^{6+} AND SEPARATION OFBIOMASS (PCBP).

For the procedure of adsorption of cr^{6+} ions were weighed on analytical scale, 2.0 g of PCBP of each of the prepared granulometry, 150 and 200 Mesh, using beads of 100 mL. Ten beaters were prepared, 5 for each of the adsorbent granulometry. In each set of 5 beaders, 50 mL were added to each residual solution containing Cr^{6+} ions, whose inferred concentrations corresponded to 40, 32, 28, 24 and 20 mg. L-1 samples A, B, C, D, E, respectively. Each set of beaders (5 beaders with PCBP 150 and 5 with PCBP 200 Mesh) with residual solutions containing Cr^{6+} ions, was arranged on heating plates with magnetic agitation, kept at a temperature of 35ºC for a period of 40 min. Figure 3 presents the procedure adopted.

Figure 3. System used for adsorption of cr^{6+} ions in heating plates with magnetic agitation and mixing in beaded of 100 mL, containing 2g biomass (PCBP) and 50 mL of residual solution containing Cr^{6+} ions (samples A to E).

Source: Elaborated by the authors (2019).

After performing the adsorption procedure, the beading containing the mixtures (50 mL of samples A, B, C, D, E and 2 g of PCBP) remained at rest for 24 h. After this time, it was observed that the mixtures presented two phases; one liquid and the other with gelatinous aspect, which made it impossible to filter them simply. Then, for the separation of these phases, the mixtures were centrifuged. From this process, the PCBP containing adsorbed Cr^{6+} ions (gelatinous aspect) and the remaining solutions of the samples ofA, B, C, D and E were obtained. After that, the solutions were submitted to simple filtration, using quantitative black belt filter paper (rapid filtration). The filtered liquid phases were properly stored in amber glass containers, ided and stored for subsequent determination of total chromium by atomic absorption spectrometry. The biomass

contaminated with Cr^{6+} ions was arranged on filter paper in an exhaust chapel at room temperature for natural drying. After drying, the material was stored in plastic bags for further studies.

3 RESULTS AND DISCUSSION

3.1 IDENTIFICATION OF FUNCTIONAL GROUPS IN BIOMASS SAMPLE (PCBP)

The identification of the functional groups present in the PCBP, performed by IR spectroscopy, is based on characteristic frequencies of radiation in the infrared region. Figure 4 shows the IR spectrum obtained from the PCBP, considering the radiation intensity used in the analysis and the wave number.

Figure 4. SPECTRUM OF IV, mostrando the functional groups of biomass PCBP (150 Mesh) that are possible generators of adsorption of cr 6+ ions.
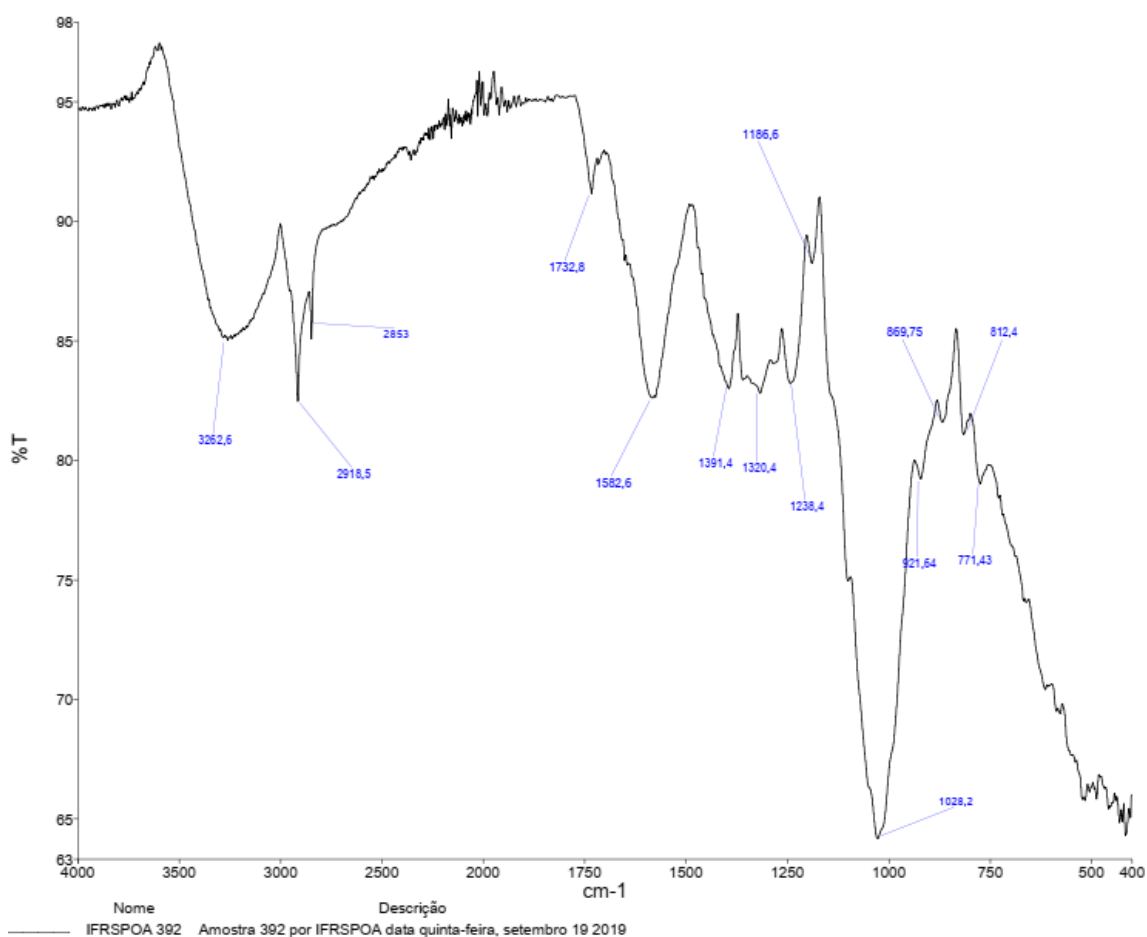
Source: Elaborated by the authors (2019).

In the spectrum shown in Figure 4, regions of absorption characteristics of bonds present in organic molecules are identified, which, compared with tabled values, allowed the identification of the functional groups presented in Table 1.

Table 1. Functional groups identified in inactive biomass (PCBP) by infrared (IR) technique by comparison with tabled data.

Functional group	Organic Function	Absorption band ($^{cm-1}$)
O-H (hydroxyl)	Apits/Phenols	3.262,6
CH$_3$, CH$_2$ (primary and secondary carbon) and, CH (tertiary carbon)	Alphatic alkanes	2.918,5 2.853,0
C=O (carbonyl)	Carboxylic Acids	1.732,8
C-C	Aromatic	1.582,6
C-O	Aromatic Ether	1.028,2

Source: Elaborated by the authors (2019).

The functional groups described in Table 1 show that it is feasible to use pcbp inactive biomass, because the studies described by BONIOLO, 2008, p.77 state that the main functional groups responsible for the adsorption of Cr^{6+} ions in banana peels are carbonyl and hydroxyl, which are present in the structure of banana peel in the form of cellulose, hemicelulose, lignin, which confer negative charges to materials of organic origin, favoring the fixation of metal ions, e.g. Cr 6+ ions, due to the positive charges of these (RONALDO *et al,* 2014).

3.2 CONTAMINATED BIOMASS

The use of biosorction to minimize contaminated liquid waste provides a decrease in the volume of effluents for disposal, by the decontamination of this material, which in the end represents an environmental gain. However, biosorcization processes end upproducing solid waste that should also be considered, since contaminated biomass generates environmental problems. Although this study does not propose evaluations on this topic, considerations on the disposal of contaminated biomass were relevant. It was observed that thepost drying of contaminated biomass, a procedure described in 2.4, there was a considerable decrease in the volume of the solid residue generated, as can be observed in Figure 5.

Figure 5: Biomass (PCBP) contaminated withcr 6+ ion after the adsorption process. (a) Biomass on common filter papers arranged in an exhaust chapel for drying at room temperature; (b) Biomass on filter papers after 24 hours of drying in an exhaust chapel at room temperature.

Source: Elaborated by the authors (2020).

The apparent decrease in adsorption residue after drying at room temperature may be related to the release of PCBP starch (biomass) during heating and also by the complexation of Cr 6+ ions with lignin, both constituents of PCBP, which resulted in gelatinization of the material. The appearance of a gelatinous phase in the mixture (PCBP + 50 mL of solution containing Cr6+ ions; samples A to E) may be associated with high

concentration of starch in cascas of ripe bananas (biomass) that can contain around 68% carbohydrates (SERET &, YANAZE, 2018).

Starches are natural polymers consisting of polysaccharides amylose and amylopectins. These compounds, in addition to increasing the ability to form agel after the granules are heated in aqueous medium, undergo structural changes, involving the rupture of the stabilizing hydrogen bridges of the internal crystalline structure of the granule ((ADITIVOS & INGREDIENTES, 2013; ALTMAN et al, 2018).

In research presented here, the mixture was heated to accelerate the kinetic process of the biosorption reaction, it is important to consider that this temperature increase causes two important effects on the adsorption process: (a) Temperature rise increases the diffusion rate of adsorbate molecules in every outer and inner boundary layer in the pores of the adsorbent particle, due to the decrease in the viscosity of the solution and (b) The temperature variation changes the equilibrium state of the adsorption to a determined adsorbate (RONALDO et al, 2014).

3.3 CONSTRUCTION OF HYPOTHETICAL ISOTERMAS

To evaluate the adsorptive process, two hypothetical isotherms were constructed: a class C, where there is constant partition of the solute between the solution and the adsorbent, and another class L, which indicates high affinity of adsorbate by the adsorbent. Initially, the amount of adsorbate retained per unit of mass of the adorbent material (q_e) in mg.g-1 $^{was\ calculated}$ using Equation 1, previously presented. As C_0 , the initial concentration inferred for each of the residual solutions (samples A to E); as C and the final concentration of adsorbate in the solution in equilibrium was considered 60% of adsorption of the initial content; m corresponded to the mass of PCBP employed (2.0 g); V, to the volume of residual solutions (50 mL). Table 2 presents the inferred values (samples A to E) used to calculate q_{and}, as explained.

Table 2. Initial concentrations of Cr^{6+} ions (C_o), concentrations of Cr^{6+} ions in $_{equilibrium}$ (C e), amount of Cr^{6+} ions adsorbed per gram of biomass (PCBP) in equilibrium (q_e).
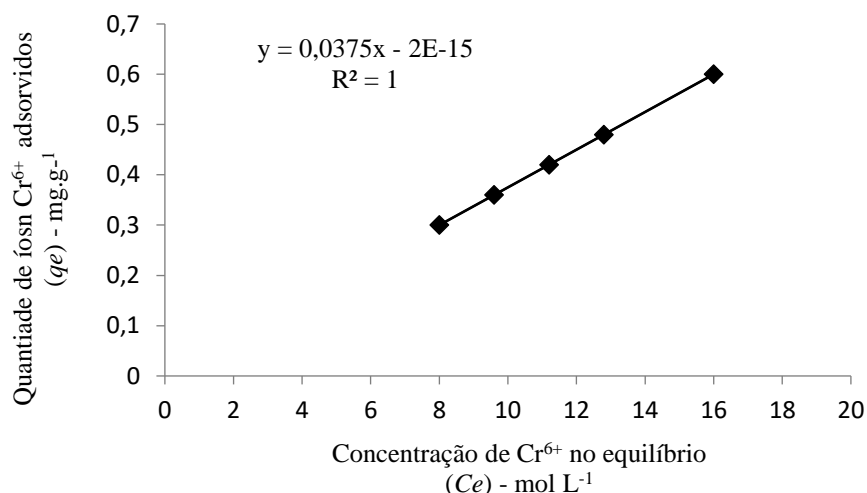
C_o (mg. L-1)	C_{and} (mg. L-1)[*]	q_e (mg.g-1)
20 (sample E)	8,0	0,30
24 (sample D)	9,6	0,36
28 (sample C)	11,2	0,42
32 (sample B)	12,8	0,48
40 (sample A)	16,0	0.60

*Considering 60% removal of Cr^{6+} ions from samples A to E in equilibrium.
Source: Prepared by the authors (2020).

The adoption of a constant adsorption percentage (60%), regardless of the initial concentrations of Cr 6+ ions in^{the} samples, resulted in a linear aspect curve ($y = 0.0375x - 2.10-15$; $R^2 = 1$) characteristic of an isotherm class C. Isotherm is presented in Figure 6, and was constructed from the data in Table 2, having the values of q e in the axis of the abscissas (x) and, and in the axis of the ordinated (y) *the values of q_e.*

Figure 6. Hypothetical Class C adsorption isotherm constructed with inferred data (Table 2) to obtain different initial concentrations of Cr^{6+} ions considering 60% cr $^{6+}$ ion removal from the solutions (samples A to E).

$$y = 0{,}0375x - 2E\text{-}15$$
$$R^2 = 1$$

Y-axis: Quantiade de íosn Cr^{6+} adsorvidos (qe) - mg.g^{-1}

X-axis: Concentração de Cr^{6+} no equilíbrio (Ce) - mol L^{-1}

Source: Prepared by the authors (2020).

The hypothetical isotherm class C (Figure 6) represents the constant affinity between Cr^{6+} (adsorbate) and adsorbent ions (PCBP), whose process is independent of the initial concentrations (C_o) of these ions. According to MEURER, 2006, this type of isotherm suggests that adsorbate particles are distributed in the solid-solution interface without any specific link with the adsorbent(PCBP). Its construction followed the theoretical basis presented and indicates the feasibility of its application for evaluation of biosorptive processes of other metal ions using different biomasses.

Another proposition was the construction of a hypothetical class L isotherm, which occurs when there is an initial high affinity of adsorbate (metal ions) by the adsorbent (biomass) that decreases as the adsorption sites are filled. This behavior indicates that the initial biosorption processincreases and, over time, reaches a limit value, suggesting the decrease in the availability of adsorption sites on the surface of the adsorbent material.

For the construction of an isotherm with the class L format it was necessaryto use different theoretical percentage scans of removal of Cr^{6+} ions, considering the initial concentrations (C_o) of samples A to E. These percentages, adopted to obtain a class L curve, ranged from 69%, for a solution of lower concentration to 50%, for the higherconcentration, respectively sample E and sample A. The amount of Cr^{6+} ions adsorbed in equilibrium (q_e) was also calculated and equation 1 was used for this.

The percentages of removal of Cr^{6+} ions, the values of the concentrations ofthese ions in the initial solutions (C_o) and in the equilibrium solutions (C_e) after the adsorption process, as well as the mass of Cr^{6+} ions adsorbed per gram of PCBP (biomass) in equilibrium (q_e), are presented in Table 3.
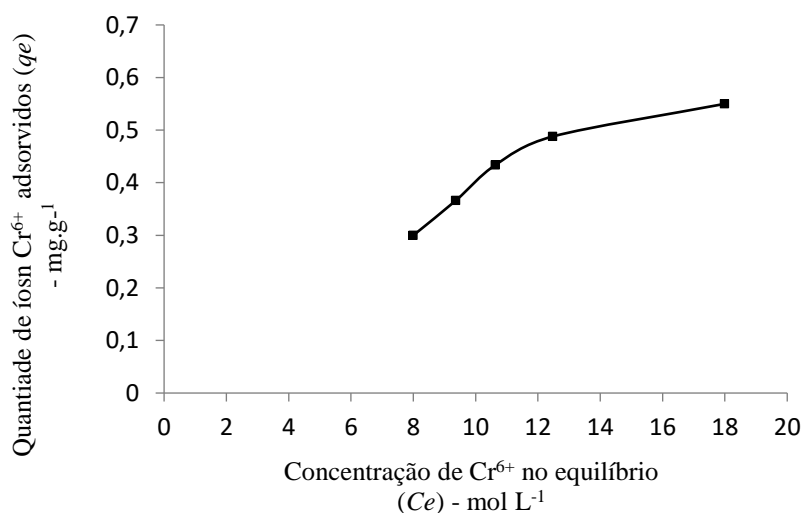
Table 3: Initial concentrations of Cr^{6+} ions (C_o), percentages of cr^{6+} ion removal, cr^{6+} ion concentrations in equilibrium (C_e) and amount of Cr^{6+} ions (samples A to E) adsorbed per gram of PCBP (biomass) in equilibrium (q_e).

C_o (mg. L-1)	Removal (%)	C_{and} (mg. L-1)*	q_e (mg.g-1)
20 (sample E)	69	6,20	0,35
24 (sample D)	67	7,92	0,40
28 (sample C)	64	10,08	0,45
32 (sample B)	60	12,80	0,48
40 (sample A)	50	20,00	0,50

Source: Prepared by the authors (2020).

Table 3 shows that *the values of q_{and}* (amount of chromium ions adsorbed per unit of mass of the adsorbent material) are higher for the solutions of higher concentration of Cr^{6+} ions in solution. However, the higher the concentration of Cr 6+ ions in solution, the lower the percentage of removal of these ions and, therefore, as the mass of adsorbent (biomass) was fixed at 2 g it is concluded that for the same amount of biomass the percentage of removal of ions (adsorbed) from the solution will be higher for solutions with lower concentrations of ions. That is, at higher concentrations of ions (adsorbate) there is a tendency to saturate the available biomass sites for adsorption, which justifiesand this trend (FRANGUELLI, 2018). With the values presented, the Class L type isotherm was constructed in Figure 7.

Figure 7. Class L hypothetical adsorption isotherm constructed from inferred data to obtain different initial concentrations of Cr^{6+} ions (samples A to E) and different adsorption percentages, as described in Table 3.

Source: Elaboratedby the authors (2020).

In continuity with this theoretical work, the hypothetical Isotherm Class L presented was linearized, which allowed new evaluations. Table 4 shows, in addition to the *parameters C_0, C_{and}, q_{and},* already presented previously, the parâmetro C_{and}/q_e, used for isotherm linearization.

Table 4 - Initial concentrations of Cr^{6+} (C_o) ions, removal percentages, cr 6+ ion concentrations in equilibrium (C_e), amount of Cr^{6+} ions (samples A and E) adsorbed per gram of biomass in equilibrium (q_e) and *parameter C_{and}/q_e*.

C_o (mg. L-1)	Removal (%)	C_{and} (mg. L-1)	q_e (mg.g-1)	C_e/q_e (g.L-1)
20 (sample E)	69	6,20	0,35	17,97
24 (sample D)	67	7,92	0,40	19,70
28 (sample C)	64	10,08	0,45	22,50
32 (sample B)	60	12,80	0,48	26,67
40 (sample A)	50	20,00	0,50	40,00

Source: Prepared by the authors (2020).

The linearized L-class isotherm has the concentration of Cr^{6+} ions in the equilibrium (C_e) in the abscissa (x) and *the values of C_{and}/q and* in the axis of the ordinates (y) as shown in Figure 8.

Figure 8. Hypothetical isotherm of class L adsorption, linearized, constructed from the data in Table 4.

$$y = 1{,}6233x + 6{,}8622$$
$$R^2 = 0{,}9903$$

Concentração de íons Cr^{6+} no equilíbrio
(C_e) - mol L^{-1}
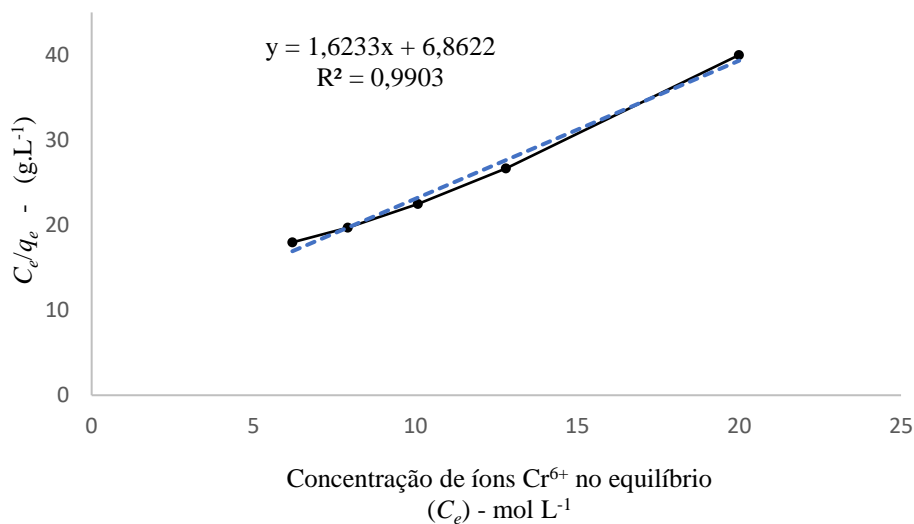
Source: Prepared by the authors (2020).

Linearization produces the equation of a line (*y = 1.6233x + 6.8622;* $R^2 = 0.9903$) that allows an evaluation of the maximumadsorption capacity of Cr^{6+} ions and also on the bonding energy of these ions to the substrate surface (PCBP) in a biosorption process, which can be represented by this type of isotherm. The angular coefficient of the line (1.6233) respondsto *parameter 1/b, being b* by definition, the maximum adsorption capacity of the metal ion to the adsorbent surface. Similarly, the linear coefficient of the line (6.8622) corresponds to parameter *1/K.b*, and the *k constant is related* to the connection ofthe metal ion to the surface of the substrate (adsorbent). With the data provided by the line equation, the values of *b* (0.62 mg.g-1) and *K* (0.24) were calculated [L.mg-1]. These values provide important information about the cr 6+ ion adsorption process in biomass (PCBP), as proposed in this study. It is found that the maximum adsorption capacity of Cr^{6+} ions (*b*) is 0.62 mg.g-1 and the interaction constant (*K*) corresponds to 0.24 [L.mg-1] adsorbate/adsorbent. These values allow evaluating the quality of the interations between adsorbate and adsorbent.

4 FINAL CONSIDERATIONS

The practical activities carried out so far demonstrated experimental feasibility presenting relevant aspects to be considered. It was possible to collect and prepare a biomass suitablefor the partition of silver banana peels. Two granulometry (150 and 200 Mesh) of silver banana peel powder (PCBP) was obtained and their characterization showed functional groups (carbonyl and hydroxyl) suitable for adsorption of Cr^{6+} ions. The system mounted for biosorption demonstrated functionality and viability in bench scale, and can be sized for larger amounts of biomass and residual solution. The contaminated solid residue, after the adsorption process, showed a decrease in volume whenair-to-air, in an exhaust chapel, which is environmentally positive for the proper disposal of this contaminated solid waste. The theoretical work developed with inferences of hexavalent chromium ion contents for residual solutions (samples A to E) and percentages for removal of these ions, based on literature data, allowed the construction of hypothetical isotherms, which can be generated in this type of procedure. The study of these hypothetical adsorption isotherms demonstrated the possibility of their use, for evaluation of adsorption processes of metal ions and in various biomasses. Considering the classes of constructed isotherms, it was possible to use specific equations and to perform calculations of several parameters: quantification ofadsorbed chromium ions (q_e); ion concentration in the equilibrium solution (C_e); maximum ability of adsorption of the ion by adsorbent (b); interaction constant adsorb/adsorbent (K). The constructed hypothetical adsorption isotherms (class C and classe L) served as models for the evaluation of the adsorptive process. These are presented as a possibility of study in future studies based on experimental data, enabling the use of other biomass and metal ions.

REFERENCES

ADITIVOS & INGREDIENTES. São Paulo: Insumos, 2013. Amidos: Fontes, Estruturas e Propriedades Funcionais. Disponível em: http://www.insumos.com.br/aditivos_e_ingredientes/materias/124.pdf. Acesso em: 2022-02-24.

ALTMANN, I.; ATZ, N. R.; ROSA, S. M. L. Desenvolvimento e caracterização de filmes biodegradáveis obtidos a partir de amido de milho: uma proposta experimental de produção de biofilmes em sala de aula. Química Nova na Escola, [S.L.], v. 40, n. 1, p. 53-58, 2018. Sociedade Brasileira de Química (SBQ). http://dx.doi.org/10.21577/0104-8899.20160104. Disponível em: http://qnesc.sbq.org.br/online/qnesc40_1/09-EEQ-81-16.pdf. Acesso em: 2022-02-24.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 10004: Resíduos sólidos – Classificação. Rio de Janeiro: ABNT, 2004. Disponível em: https://analiticaqmcresiduos.paginas.ufsc.br/files/2014/07/Nbr-10004-2004-Classificacao-De-Residuos-Solidos.pdf. Acesso em: 2022-02-24.

ATSDR. Agency for Toxic Substances and Disease Registry. Toxicological profile for Chromium 2012. Atlanta, GA: Departamento de Saúde e Serviços Humanos dos EUA, Serviço de Saúde Pública. Disponível em: https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=62&tid=17. Acesso em: 2022-02-24.

BONIOLO, Milena Rodrigues. Biossorção de urânio nas cascas de banana. 2008. Dissertação (Mestrado em Tecnologia Nuclear - Materiais) - Instituto de Pesquisas Energéticas e Nucleares, Universidade de São Paulo, São Paulo, 2008. doi:10.11606/D.85.2008.tde-19082009-155206. Acesso em: 2022-02-24.

BRASIL, RESOLUÇÃO CNE/CEB N ° 06 de 20 setembro 2012, Define Diretrizes Curriculares Nacionais para a Educação Profissional Técnica de Nível Médio. Disponível em: http://portal.mec.gov.br/index.php?option=com_docman&view=download&alias=11663-rceb006-12-pdf&category_slug=setembro-2012-pdf&Itemid=30192. Acesso em: 15-11- 2019.

BRASIL, RESOLUÇÃO CNE/CP N° 1 de 5 janeiro 2021. Define as Diretrizes Curriculares Nacionais Gerais para a Educação Profissional e Tecnológica. Brasília, DF, 2021. Disponível em: http://portal.mec.gov.br/index.php?option=com_docman&view=download&alias=167931-rcp001-21&category_slug=janeiro-2021-pdf&Itemid=30192. Acesso em: 10- 01- 2021.

CARMO, Taciana Soares Do. Biossorção de Cromo Hexavalente em Cascas de Frutas. 2013. Dissertação (Mestrado em Engenharia Química) - Universidade Federal de Uberlândia. Uberlândia, 2013. Disponível em: https://repositorio.ufu.br/bitstream/123456789/15213/1/BiossorcaoCromoHexavalente.pdf. Acesso em: 2022-02-24.

CETESB - Companhia Ambiental do Estado de São Paulo. Ficha e informação toxicológica; Crômio e seus compostos. São Paulo. 2017. Disponível em: https://cetesb.sp.gov.br/laboratorios/wp-content/uploads/sites/24/2013/11/Cromio.pdf. Acesso em: 2022-02-24.

DIAS, R. F. C.; FELISBERTO, R.; RAMOS, A. F.; FARIA, R. R.; DIAS, F. M. F.; DANTZGER, D. R. C. Biosorption of Cr (III) from Aqueous Solution Using Banana Peel Powder. Revista Processos Químicos, v. 13, n. 26, p. 11-18, 7 mar. 2020. Disponível em: https://doi.org/10.19142/rpq.v13i26.533. Acesso em: 2022-02-24.

EMBRAPA - Produção Brasileira de Banana em 2019. Disponível em:http://www.cnpmf.embrapa.br/Base_de_Dados/index_pdf/dados/brasil/banana/b1_banana.pdf. Acesso em: 2022-02-24.

FRANGUELLI, F. P. Potencial e Cinética de Adsorção de Cromo Hexavalente por Fibra de Coco in natura (Cocos nucifera). Orientador: Katia Tannous. 2018. 60 f. Dissertação (Mestrado) – Universidade Estadual de Campinas, Programa de Pós-Graduação em Engenharia Química, Campinas, 2018. Disponível em: http://bdtd.ibict.br/vufind/Record/CAMP_4c15838e876f2dad4ca9fd44f9ba89e7. Acesso em: 2022-02-24.

GILES, C. H. & SMITH D.. A general treatment and classification of the solute adsorption isotherm. I. Theoretical. Journal of Colloid and Interface Science, [S.L.], v. 47, n. 3, p. 755-765, jun. 1974. Apud Franguelli, F. P.; Dissertação (Mestrado). Universidade Estadual de Campinas, Brasil, 2018. Disponível em: http://dns2.asia.edu.tw/~ysho/YSHO-English/1000%20WC/PDF/J%20Col%20Int%20Sci47,%20755.pdf. Acesso em: 2022-02-24.

ISA, M. H. et al.; Removal of chromium (VI) from aqueous solution using treated oil palm fibre. Journal of Hazardous Materials, [S.L.], v. 152, n. 2, p. 662-668, abr. 2008.Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S030438940701028X. Acesso em:2020- 07-12.
MARTINS, B. E. B. et al. Remoção de metais da água utilizando cascas de bananas frescas. Brazilian Journal of Development, Curitiba, v.7, n.4, p. 36806 - 36817. apr 2021. Disponível em: https://brazilianjournals.com/index.php/BRJD/article/view/27957/22124. Acesso em: 2022-02-24.

MEURER, E. J.; Fundamento de Química do Solo. 3ª ed. Porto Alegre: Evangraf, 2006.

RONALDO et al. Adsorção: Aspectos teóricos e aplicações ambientais. Imprensa Universitária da Universidade Federal do Ceará (UFC). Av. da Universidade, 2932, fundos – Benfica – Fortaleza-Ceará. 2014. Disponível em: https://repositorio.ufc.br/bitstream/riufc/10267/1/2014_liv_rfdnascimento.pdf. Acesso em: 2022-02-24.

SANTOS, E. A. dos. Síntese e caracterização de carvões ativados e compósitos C/Fe produzidos a partir de tortas de biodiesel para remoção de Cr (VI) em meio aquoso. 2015. Tese (Doutorado em Ciências – Química). Departamento de Química. Instituto de Ciências Exatas. Universidade Federal de Minas Gerais, Belo Horizonte, 2015. Disponível em: https://repositorio.ufmg.br/bitstream/1843/BUBD-A2KFV4/1/tese___vers_o_final_04_set_com_folha_de_aprova__o.pdf. Acesso em: 2022-02-24.

SERET LION, A. V. S.; YANAZE, R. Y. Obtenção e caracterização de farinha de cascas de bananas verdes e maduras. 2018. Trabalho de Conclusão de Curso (Curso Superior de Tecnologia em Alimentos). Universidade Tecnológica Federal do Paraná – UTFPR, Câmpus Londrina, 2015. Disponível em: http://repositorio.roca.utfpr.edu.br/jspui/bitstream/1/12403/1/LD_COALM_2018_2_01.pdf. Acesso em: 2022-02-24.