An alternative method of removing Cr (VI) from aquatic solution using chemically modified cone biomass and *Fomitopsis pinicola*

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Abstract. We report the adsorption of Cr (VI) ions from aqueous solution by forest waste. Two adsorbents were prepared from cone biomass and *Fomitopsis pinicola*. To study the kinetics of both were used three particular size (<0.5, 0.5-1, 1-2 mm). It was found that adsorbents chemically modified with a HCl (activation 2mol/L, activated for 60 min) demonstrated better Cr(VI) removal capabilities as compared to pure adsorbents in terms of their adsorption rate. The optimum conditions for removal of Cr(VI) were found to be particular size <0.5 mm, pH=1, contact time 10 min, adsorbent dosage 20g/L, concentration of Cr(VI) 100 mg/L, temperature 25 ± 1°C, rpm 200. The percent removal at these optimum conditions was found to be 100 % for both biosorbents. The Langmuir model fitted the equilibrium data better than the Freundlich isotherm. The maximum uptake capacities for 40.98 mg/g and 45.05 mg/g for cone biomass and *Fomitopsis pinicola*, respectively. To study the effect of other ions on the Cr (VI) removal by both biosorbents, electroplating industry wastewater was collected from an industry. Overall, the experimental results suggest that cone biomass and *Fomitopsis pinicola* could be used as low cost alternative adsorbents for the treatment of low concentration Cr (VI) containing wastewater.

1. Introduction
The issue of heavy metals due to their toxicity, persistence and bioaccumulation ability in the environment is still paid much attention. Their presence in industrial wastewater, regarding their discharge into surface water, often presents a big problem. These problematic metals also include chromium, which is used in many industrial applications. The wastewater from these industries contains Cr (VI) and Cr (III), in the concentration range from tens to hundreds of milligrams per litre. The hexavalent form of chromium is more toxic than trivalent chromium as it persists indefinitely in the environment complicating its remediation [1].

For the removal of Cr (VI) from the aqueous environment, a wide range of physical and chemical processes can be used. Unfortunately, many of them are very expensive due to high amount of used chemicals. Mostly abroad, attention is paid to the use of sorption properties of various low-cost, easily accessible materials as an alternative technology. The attractive features of biosorbents include their high versatility, relatively good selectivity of metal and in some cases, the high adsorption capacity, particularly in the low concentration range. However, it should be noted that not all naturally available materials which have been studied so far, had satisfactory adsorption capacity in the tested concentration range. In view of the fact that there is still a need to develop new innovative biosorbents which would be economically advantageous and useful, the possibility of the removal of Cr (VI) using a variety of low cost materials has also been also investigated. Up to now, a large amount of different materials has
been studied for the purpose of the removal of large amounts of dissolved metals or organic substances. Tested biosorbents can be basically divided into the following categories: bacteria (e.g. *Bacillus subtilis*), fungi (e.g. *Rhizopus arrhizus*) [2], yeast (e.g. *Saccharomyces cerevisiae*), algae (e.g. *Chlorella vulgaris*, *Spirogyra* sp.) [3], industrial waste (e.g. *S. cerevisiae* of the waste biomass from the fermentation and food industry) [4], building material waste, [5] agricultural waste (e.g. residues of maize, rice, nuts, seeds and peels of fruit), ash originating from plant biomass combustion [6] and other polysacharide materials, etc.

The article summarizes knowledge gained from our research on the use of low-cost material for the removal of Cr (VI) from the aquatic environment. Used biomass of cone and *Fomitopsis pinicola* is easily accessible forest waste materials. The exchange/sorption properties of these biosorbents are due to presence of some functional groups, such as carboxylic, hydroxyl, etc., which have high affinity for metal ions.

2. Material and methods

The real challenge in the field of biosorption is to identify the mechanism that controls the adoption of adsorbed metal by biosorbents. One of the conditions within the study, was to preserve the same conditions of the biosorption process to evaluate the individual biosorbents and compared them to each other.

2.1 The methodology of preparation of biosorption material

To study the removal of Cr (VI) from the aqueous solution, the following biosorbents were used: bracket fungus (*Fomitopsis pinicola*) and mixture of cones of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in a ratio of 1:1. Pre-treatment was uniform for all biosorbents. To ensure the binding interactions and also for better functionality and usability of biosorbents in the process of biosorption, the pre-dried biomass was further granularly, thermally and chemically modified. For granular modification, the material was first crushed using a mobile crusher of the type Raptor 624 (Werco, Czech Republic) and for the fine fraction, the laboratory mill of the type IKA A 11 basic (IKA - Werke, Germany) was used. Prior to sieving, the samples were dried at 105 ± 1 °C for about 4 h (to remove the sticky effect). For the thermal treatment of the biosorbent samples by drying, the dryer of the type ECOCELL standard (MMM Group, Czech Republic) has always been used. The granular modification by sieving to the desired grain size of 1.0 – 2.0 mm, 0.5 to 1.0 mm and <0.5 mm, for the purpose of studying the effect of the biosorbent particle size on the adsorption mechanism was performed through a set of stainless steel sieves of the brand Retsch (Germany).

Chemical modification of biosorbents using activating agents should ensure making functional groups active in the process of biosorption accessible. Due to the nature of the studied metal, HCl with various molar concentrations (0.1 mol l\(^{-1}\); 1.0 mol l\(^{-1}\) and 2.0 mol l\(^{-1}\) ) was used for activation. Samples of biosorbents were activated by stirring in a shaking incubator of the type GFL 3031 (Helago-CZ, Czech Republic) at a constant speed of 150 rpm. The activation length proceeded for each grain size class and each molar concentration of activating agent in the following intervals: 15, 30, and 60 min. After removing the supernatant, the activated material was repeatedly thoroughly washed with redistilled water. The effectiveness of washing away the activating agent residues was monitored by measuring pH value after washing with a pH meter of the type ION 340i (WTW, Czech Republic).

2.2 The methodology of modelling of the biosorption process

All adsorption studies were due to the simplicity, performed by means of static (so called “batch”) mode. Modelling of adsorption kinetics was applied to determine the most ideal exposure time that was necessary for the biosorption of Cr (VI) and equilibration between the two phases biosorbent - adsorbate. All adsorption experiments were carried out by mixing 1.000 0 ± 0.02 g of the biosorbent dried to constant weight with 50.0 ml of chromium solution of desired concentration (100 mg L\(^{-1}\)). The temperature during the experiment was kept constant at 23 ± 1 °C (controlled by the temperature sensor). Samples were shaken in a shaking incubator of the type GFL 3031 (Helago-CZ, Czech Republic) at 150 rpm. After a predetermined time, interval (10, 20, 30, 40, 50, 60, 120, 180 and 240 min), the suspension was filtered through a membrane filter PRAGOPOR 6 (PRAGOCHEMA spol. s.r.o.; it was used for all filtration).
The initial concentration of Cr (VI) in the model solutions and the equilibrium residual concentrations of Cr (VI) in the filtrate after the biosorption were analysed by the spectrophotometric method by creating a violet coloration with 1.5-diphenylcarbazide in the apparatus DR 2800 (Fa HACH LANGE GmbH, Germany) at 540 nm. All experiments were conducted in triplicate and the percent error in the results was within ±3 %.

The percentage of the amount of hexavalent chromium removal was expressed as removal efficiency (R %) and calculated according to the following equation:

$$ R(\%) = \frac{c_i - c_f}{c_i} \cdot 100 $$

where are:

$c_i$ initial concentration of metal in solution volume, (mg L$^{-1}$),

$c_f$ the equilibrium concentration of the adsorbate in solution, (mg L$^{-1}$),

Adsorption equilibrium data at 25 ± 1 °C, mixing speed 200 rpm, the concentration of the chemically modified biosorbents 20 g L$^{-1}$, pH = 1.1, particular size <0,5mm was modelled using Langmuir and Freundlich isotherms (both in non-linearized and linearized form). The equilibrium data were getting by variable initial chromium concentration (100, 200, 300, 400, 500, 600, 700, 900 and 1,000 mg L$^{-1}$), while the other parameters are kept constant.

3. Results and discussion

The unmodified sorbents have much lower adsorption capacity than the chemically modified ones. During the kinetics study were therefore used a chemically modified sorbents (hydrochloric acid, concentration of 0.1, 1 and 2 mol L$^{-1}$) and grain size classes of <0.5, 0.5–1.0 and 1–2 mm. The chemical modification of HCl at a concentration of 0.1 mol L$^{-1}$ was not very efficient, so the results are not presented in the work nor discussed. Based on the evaluated measured data obtained during the kinetics study can be stated that the use of biosorbents report satisfied results, especially these with low grain size (<0.5 mm). Based on the best adsorption efficiency, the grain size <0.5 mm was chosen as a limiting parameter for all biosorbents. Also, most of authors consistently states higher adsorption capacity when using fine-grained material. This is mainly due to a larger surface area of the active particles, so a larger number of binding sites are accessible. Therefore, the particles larger than 2.0 mm were not studied, because, compared to smaller particles, they contribute to increasing the diffusion resistance to mass transfer more. On the basic of kinetics studies were therefore found that the grain size 0.5 mm and chemical treatment by hydrochloric acid about concentration 2 mol L$^{-1}$ activated for 60 min (for both biosorbents) is the most convenient for biosorption use. For such modified sorbent was detected the highest adsorption capacity 100 % for both biosorbents after 20 min.

In the process of the biosorption, pH is one of the most important parameters that can affect the course of biosorption very significantly. The pH of the aqueous solution has an influence on the speciation of chromium, and also the dissociation of the active functional groups (-OH, -COOH, -NH$_2$) occurring on the surface of biosorbents. Therefore, the adsorption of chromium is critically linked to the solution pH. At low pH values, the functional groups on the surface of the biomaterial are protonated, and thus the access of cationic species is restricted due to repulsive forces. Conversely, when pH increases, the degree of protonation decreases, and the functional groups thus become negatively charged (pH > pK$_A$). An aqueous solution of Cr (VI) exists in five anionic forms: H$_2$CrO$_4$, HCrO$_4^-$, CrO$_4^{2-}$, HCr$_2$O$_7^-$, Cr$_2$O$_7^{2-}$, whose distribution depends on the pH value, but also on the total concentration of chromium. At the solution pH between 2.0 and 6.0, ions of Cr (VI) in the solution are probably in the form of HCrO$_4^-$ a Cr$_2$O$_7^{2-}$. At lower pH (pH < 2.0), the main types are Cr$_6$O$_{13}^{2-}$, Cr$_5$O$_{10}^{2-}$. These anionic species can then be adsorbed to the protonated active sites present on the biosorbent surface. Due to the speciation of the studied metal and the fact that the adsorption of metal in the form of anions is most effective under acidic conditions, only pH range from 1.1 to 6.0 has been tested for the study of the effect of pH. The pH values >6.0 have not been studied, since there is no confirmation of adsorption of Cr (VI) at pH values above 6.0 due to the competition of anions HCrO$_4^-$, Cr$_2$O$_7^{2-}$ and OH$^-$ for the adsorption sites. The consumption of protons H$^+$
through reduction of Cr (VI) leads to the rise of pH of the solution. It is therefore very important to check it in the system during biosorption. This was avoided by using buffers, so the pH value was constant throughout the experiment.

Within the study of the influence pH depending on the exposure time, it has been experimentally demonstrated that lowering the sorbate pH value to 1.0–2.0 significantly improved the adsorption capacity for all tested biomaterials (F. pinicola by 50 min and the mixture of cones by 30 min). There was a sharp decline in percent adsorption with increase in pH of the aqueous solution (from 1.0–6.0). Chromium removal decreased from 100 % to 18.0 % in cone biomass and 100 % to 28.0 % in F. pinicola. As maximum chromium removal was at pH 1.0, hence, it was taken as the optimal pH value for other experiments. The mechanism of Cr (VI) in an acidic environment was probably its reduction to Cr (III) by direct reduction reactions and adsorption of Cr (III) ions at higher pH. At very low pH (pH = 1.1), the anions of Cr (VI) will reduce to the Cr (III) ions, but these will be poorly adsorbed by the biosorbent due to electrostatic repulsive forces. At the contact of Cr (VI) with the electron-donor group of biomaterials that has a lower reduction potential than chromium (VI), Cr (VI) is reduced to Cr (III) in the aqueous phase (direct mechanism). The ions of Cr (III) then remain in the aqueous solution or form complexes with Cr-linker groups which are found on the surface of the biomaterial. Since no measurable content of Cr (III) was found in the filtrate (pH < 3) during the experiments, the possibility of post complexation contribution in the removal of Cr (VI) can be considered. However, this is only conjecture. To confirm this hypothesis, a more detailed analysis must be done (SEM, FT-IR, etc.). Also, the great majority of authors report that the highest efficiency in the removal of Cr (VI) was achieved with pH in the range of 1.0 to 2.0. On the other hand, it is necessary to mention the fact that many studies show that Cr (VI) was removed from the aqueous solution biosorbents via adsorption between positively charged adsorption sites on the surface of the adsorbent and anionic Cr (VI). Mohan and Pittman also pointed out that the conclusions of the removal of Cr (VI), which are reportedly carried out by electrostatic mechanisms, could arise due to incorrect interpretation of the obtained information [7]. It is precisely because of measurement errors in speciation of chromium in the aqueous phase, insufficient contact time required for the equilibrium and a lack of information on the oxidation state of chromium bound to biosorbents. Currently, the actual mechanism for adsorption of Cr (VI) with natural biomaterials under acidic conditions is generally considered the adsorption coupled with reduction. Park et al. reported that Cr (VI) can be removed from the aqueous solution natural biomaterial through the mechanism of both direct and indirect reduction [1]. The indirect reduction mechanism is rather complicated and essentially consists of three steps. First, the binding of anionic Cr (VI) to the positively charged groups on the surface of biomaterials (amino and carboxyl groups) occurs. In the second step, it is reduced to Cr (III) through the adjacent electron-donor groups, which is then accompanied by the release of Cr (III) in the aqueous phase due to repulsion between the positively charged Cr (III) and positively charged groups on the surface of biomaterials or complexes of Cr (III) with adjacent groups.

Generally, the adsorption rate is controlled by the external diffusion of external or internal diffusion, or both. Applying the model of the pseudo-first order, it was found that the correlation coefficients are very low, which indicates a bad quality of linearization, and the said model is not suitable for the description of experimental data. In addition, the adsorption capacity \( q_{\text{theor}} \) values obtained by this method were in contrast with the experimental values \( q_{\text{exp}} \). Based on this finding, the reactions could not be classified as first order reaction in either of the tested biosorbents. One explanation with regard to the differences between experimental and theoretical values \( q \) may be the fact that during the biosorption there is a certain delay, probably because of the thin layer or the influence of external resistance at the beginning of the biosorption. Considering the fact that this model, which is suitable for homogeneous surfaces, was not applicable for the studied biosorbents, it can be concluded that there will probably be a larger number of the sites of adsorption and other effects of the mass transfer. The model of the pseudo-second-order is based on the assumption that the rate limiting the speed may be chemical adsorption involving valence forces through sharing or exchange of electrons between the adsorbent and adsorbate. Unlike the model of the pseudo-first order, this model sufficiently predicts the adsorption behavior throughout the adsorption period. Therefore, it may be considered more acceptable to represent kinetic data. Moreover, within the experiments, the
equilibrium adsorption capacities obtained using this model were much more reasonable than those obtained using the model of pseudo-first order. When comparing the expected results with experimental data \( q_{\text{theor}} \), a very good consensus was demonstrated. According to the model of the pseudo-second order, the rate constant \( k_2 \) is related to the overall speed of the biosorption process. The obtained data confirm that the rate at \( pH = 1.1 \), is much higher than that in the experiments where the \( pH \) value was not modified. In the case of \( F. \) pinicola and a mixture of cones, a multiple increase of the overall rate of responses have been reported. And what is even more significant, in an acidic environment (\( pH = 1.1 \)) the initial speed of the removal of Cr (VI) increased sharply. Based on the model of the pseudo-second order, it was found that during the first ten minutes, under the given conditions, \( F. \) pinicola adsorbed 6 g of Cr (VI) per one gram of the biosorbent for one minute, and in the case of a mixture of cones, it was 1 g. This is a very important factor for the proposal and optimization of processes in the industry. The rate of the mass transfer from the solution of Cr (VI) on the solid surface of the biosorbent depends to some extent on the intensity of stirring. Therefore, the stirring speed also plays an important role in the mass transfer of chromium from the solution on the surface of the adsorbent. Within the experiments, the rotational speed in the range of 100-300 rpm was tested while keeping the other biosorption parameters constant \( (c_i = 100 \text{ mg L}^{-1}; t = 25 \pm 2 \text{ °C}; c_s = 20 \text{ g L}^{-1}). \) However, no significant effect of stirring speed in the stated range of the stirring speed was found. To study the biosorption equilibrium, but speed of 200 rpm was selected, because by visual inspection, a much better contact between the biosorbent and adsorbate was ensured. The selected stirring speed of 200 rpm provided the best homogeneity of the mixture suspension. Higher speeds were already excluded due to the possible occurrence of vortex during the high-speed stirring. There was a risk that the suspension would not be homogeneous and adsorption of Cr (VI) could thus be negatively affected. The removal of Cr(VI) was also studied by variable adsorbent dose \((1.000, 2.000, 3.000, 4.000, 5.000 \text{ and } 6.000 \text{ g/50 mL})\) in aqueous system while keeping initial Cr(VI) concentration \((100 \text{ mg L}^{-1})\), temperature \((25 \pm 1 \text{ °C})\), stirring speed \((200 \text{ rpm})\), contact times \((10 \text{ min})\). We observed that removal efficiency of the adsorbents generally increased with increasing the quantity. It is since the availability of exchangeable sites for the ions. The results showed that Cr (VI) removal increased from 37.7 % to 93.8 % and 50.3 % to 100.0 % in cone biomass and \( F. \) piniola, respectively, as dose increased from 20 to 120 g L\(^{-1}\). At higher adsorbent dose, more exchangeable sites are available for Cr (VI) adsorption. However, the adsorption capacity decreased with increase in adsorbent dosage. This may be due to overcrowding of adsorbent particles which leads to their overlapping.

Generally, the temperature has a direct influence on the process. The adsorption experiments were conducted in the temperature range of 20, 30 and 50 \( \text{°C} \) at constant Cr(VI) concentration \((100 \text{ mg L}^{-1})\), \( pH \) \((1.0)\), adsorbent dose \((20 \text{ g L}^{-1})\) and contact time \((10 \text{ min})\). It was observed that, Cr (VI) adsorption by both biosorbents is 100 %. Values of \( \Delta G^0 \), \( \Delta H^0 \), \( \Delta S^0 \), indicate that the adsorption process was spontaneous in nature for the uptake process. The positive \( \Delta H^0 \) value confirms the endothermic nature of sorption process. Since diffusion is an endothermic process. Negative values of \( \Delta G^0 \) indicate the feasibility and spontaneous nature of adsorption process. The value of \( \Delta G^0 \) doesn’t change with increasing temperature. This shows that an increase in temperature doesn’t favors the removal process. The positive value of \( \Delta S^0 \) confirms that adsorption on cone biomass and \( F. \) piniola is a combination of the above said two simple processes.

Comparison of adsorption capacity of the biosorption of one metal can best be realized based on the adsorption isotherm for one metal. So that the comparison of two or more biosorbents could be objective, the biosorption was always performed under the same conditions. They were limited by the environmental factors under which the biosorption could take place (\( pH \), temperature). The adsorption data were described using two models: Langmuir and Freundlich adsorption isotherms. Both models have been extensively used by other authors who studied the adsorption equilibrium between the solution of metal and the solid phase of the biomass.

Although the Langmuir model does not provide any clarification of mechanistic aspects of biosorption, but it can inform on the reception capability, and it is able to reflect the normal behavior of the equilibrium biosorption process. In practice, it is most often used because it contains two useful and
easily conceivable parameters \((Q_{\text{max}}\) and \(K_L\)), which are easy to understand because they reflect two important characteristics of the biosorption system. In its application to molecular species (biosorbents), it is necessary to have in mind, however, that these assumptions of these initial relationships actually come from experiments carried out with activated carbon as a solid adsorbent. A monomolecular layer on which deposition of sorbates occurs, assumes adsorption on the surface, which is not always the case of complete biosorption.

The Langmuir model assumes that the uptake of metal ions occurs on a homogeneous surface by monolayer adsorption without any interaction between adsorbed ions. The plots of \(c_f/q\) versus \(c_f\) are linear which indicates that the data fitted reasonably well to the Langmuir isotherm in the present adsorption study. The values of \(Q\) and \(b\) were calculated from the slope and intercept of the Langmuir plot of \(c_f\) versus \(c_f/q\) and are reported in Table 1.

Table 1. Langmuir and Freundlich model constants for cone biomass and \(F.\) pinicola.

| Parameter | Cone biomass | \(F.\) pinicola |
|-----------|--------------|----------------|
| **Langmuir constants** | | |
| \(Q\) (mg g\(^{-1}\)) | 40.98 | 45.05 |
| \(b\) (L·mg\(^{-1}\)) | 0.4527 | 1.116 |
| \(R^2\) | 0.9960 | 0.9932 |
| **Freundlich constants** | | |
| \(K_f\) (mg g\(^{-1}\)) | 10.03 | 8.13 |
| \(n\) (L mg\(^{-1}\)) | 3.06 | 2.06 |
| \(R^2\) | 0.7632 | 0.8417 |

Linear plots of ln \(q\) versus ln \(c_f\) showed that the Freundlich isotherm was no longer so representative for the Cr (VI) adsorption by both types of adsorbent tested. Values of \(K_f\) and \(n\) were calculated from the intercept and slope of the plot. Both parameters, \(K_f\) and \(n\), affect the adsorption isotherm. The larger the \(K_f\) and \(n\) values, the higher the sorption capacity. The magnitude of the exponent \(n\) gives an indication of the favorability of the adsorption. It is generally stated that values of \(n\) in the range 2–10 represent good, 1–2, moderately difficult and less than 1, poor adsorption characteristics.

The essential characteristics of Langmuir isotherm can be explained in terms of dimensionless constant separation factor \(R_L\). Thus, constant separation factor \(R_L\) is a positive number whose magnitude determines the feasibility of the adsorption process. The \(R_L\) values for each of the different initial concentrations used are between 0 and 1 indicating favorable adsorption of Cr (VI) onto differently modified cone biomass and \(F.\) pinicola (Table 2).

Table 2. Langmuir dimensionless constant separation factor for cone biomass and \(F.\) pinicola.

| \(c_i\) mg L\(^{-1}\) | Cone biomass | \(F.\) pinicola |
|----------------|--------------|----------------|
| 100 | 0.0211 | 0.0087 |
| 200 | 0.0115 | 0.0047 |
| 300 | 0.0077 | 0.0031 |
| 400 | 0.0057 | 0.0023 |
| 500 | 0.0043 | 0.0018 |
| 600 | 0.0038 | 0.0015 |
| 700 | 0.0032 | 0.0013 |
| 800 | 0.0028 | 0.0012 |
| 900 | 0.0024 | 0.0010 |
| 1 000 | 0.0022 | 0.0009 |
The experience from the batch studies have shown that the removal of Cr (VI) decreased with the increasing initial concentrations of Cr (VI), which suggests that the adsorbents have a limited number of sites, which were saturated above a certain concentration, and thus no further adsorption occurred. To study the effect of other ions on the Cr (VI) removal by cone biomass and *F. pinicola*, electroplating industry wastewater was used. The Cr (VI) concentration in the industrial wastewater was 1.51 g L\(^{-1}\). pH value of this wastewater was adjusted to 1.0 with HCl after filtration and adsorbent dose was maintained at 20 g/L for 10 minutes. Percent removal was found to be 62.9 % and 45.7 %, respectively for cone biomass and *F. pinicola*. Percent removal of Cr (VI) in real water was much lower as compared to the simulated sample. The difference between the Cr (VI) uptake from the simulated sample and the effluent may be attributed to the presence of other ions and impurities like Cd, Zn, Ni, Mn etc. They may compete with chromium for binding sites thus leading to lesser Cr (VI) removal in the effluent making the metal unavailable for the adsorption by both the adsorbents. While in the aqueous solution, only, Cr(VI) metal ions were present, so the binding sites were occupied by only Cr(VI) ions, thus, leading to higher percent removal from synthetic wastewater.

4. Conclusion
This study demonstrated that Cr (VI) adsorption by hydrochloric acid treated cone biomass and *F. pinicola* adsorbents depends on pH, initial Cr (VI) concentration, adsorbent dose, contact time and effect of other ions. Percent removal was 100 % for both biosorbents at pH 1.0. Percent removal of Cr (VI) decreased with increase in initial Cr (VI) concentration but increased with increase in adsorbent dose. Thermodynamic parameters reveal that adsorption process is endothermic in nature. Sorption of Cr (VI) obeys Langmuir model for both the adsorbents. From the kinetic studies, it is observed that adsorption of Cr (VI) is very rapid in initial stages and decreases with approaching equilibrium. It may be concluded that easy availability and suitability for production of carbonaceous adsorbents from biomass makes it one of the materials that can be used for removal of chromium from aqueous medium. It helps to reduce the cost of waste disposal and most importantly would provide a potentially inexpensive alternative to existing commercial techniques.

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