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Utilization of Agricultural Waste: A Case Study of Modified Rice Husk with Sorbic Acid to Remove Hexavalent Chromium Cr^{6+} from Aqueous Water

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Abstract Hexavalent chromium (Cr^{6+}) poisoning has been a serious concern for decades. Removal of Cr^{6+} in water in developing countries with simple and economical methods should be considered. Hence, the study aims to modify rice husk with sorbic acid (SRH) as an eco-friendly and economical adsorbent to remove Cr^{6+}. The chemical structure and its surface morphology were investigated through Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy (SEM) analysis. Besides, driving effects among important independent variables were precisely carried out with pH (2-11), contact time (1-8 days), concentration dosage (1-4 g/L), and temperature (283-303K). The results indicate that SRH appeared in some new stretching vibration groups including OH- and COO- on FTIR analysis. Furthermore, its surface was shown significantly roughly with many deep holes in SEM analysis. It could be impressive evidence for efficient adsorption. It was demonstrated by the adsorption capacity being remarkably increased – being shown by the uptake efficiency of 99.9% Cr^{6+} at pH 2 and 4g/L concentration dosage with an initial Cr^{6+} concentration of 100 mg/L. In addition, the modeling study was well fitted with Langmuir, Freundlich, and Pseudo-second order through favorable coefficient correlation (R^2). Its adsorption capacity was reported at 97.09 mg/g by the Langmuir model. For the thermodynamic study, its parameters indicate that the adsorption of Cr^{6+} is spontaneous and that physisorption contributes greatly to the removal of Cr^{6+}.

Keywords Hexavalent Chromium, Rice Husk, Adsorption, Sorbic Acid, Removal, FTIR, SEM

1. Introduction

Hexavalent chromium (Cr^{6+}) is known as one kind of metallic element [1]. It is widely used in many industrial activities such as electroplating, textile manufacturing, pigments and dyes, chemical synthesis, refractory production, leather, and wood preservation, etc. [2–4]. Because its compounds feature corrosion resistance, durability, and hardness [5–7]. Besides, many industrial processes have reported that two major forms of strongly oxidizing Cr^{6+} are known as dichromate ($Cr_2O_7^{2-}$) and chromate (CrO_4^{2-}) ions [8]. In particular, pH levels significantly affect on species of Cr^{6+}. At pH < 1, the solution is mostly contributed by H_2CrO_4, when pH from 2-6.5, $HCrO_4^-$ is exclusively dominated, and at higher pH, this form is replaced by CrO_4^{2-} [9–11]. Because of its wide application and diverse variation in environmental conditions, the likelihood of hexavalent chromium poisoning is very high.

Therefore, a number of cases have been formally reported about the detrimental effects of Cr^{6+} on the

human body through inhalation, ingestion, and skin [12]. According to some international estimates, more than 558.000 American workers have been contacted with airborne containing Cr^{6+} compounds at their workplaces [13]. Furthermore, around 1.045.500 U.S. workers have been exposed to Cr^{6+} in the cement and primary construction industries [7], etc. As a result, populous techniques for removal of Cr^{6+} have been widely used and promoted, these are known as coagulation, ion exchange, advanced oxidation process [14], filtration with membrane [15], precipitation [16,17], and adsorption methods, etc. [18]. However, the major concern regarding economy and simplicity with an effective method that leads to the adsorption techniques can be chosen as an inexpensive and effective method for handling heavy metals in drinking and wastewater. Hence, adsorbents generated by agricultural wastes, these are famous as activated carbon or modified activated carbon, bio-adsorbents, etc. This technique is less expensive, readily available, profitable, and, outstanding performance for removal pollutants [14,19]. Since many researchers are interested in utilizing agricultural residues such as tea waste [20], hazelnuts husk [21], sawdust [22], moringa oleifera bark [23], coconut shell carbon [24], peanut hull ash [25], bagasse fly ash, and rice husk [26], etc to eliminate toxic metals (Cu^{2+}, Pb^{2+}, Cr^{6+}, Zn^{2+}, Cr^{3+}, As^{3+}, etc.). Among various adsorbents, rice husk has emerged as one of the most popular agricultural wastes. It is available in large quantities, low-cost, and easy to regenerate after use so it may have potential as a potential adsorbent [27–29]. Because it is insoluble in water, has good chemical stability [30], and the high mechanical strength - making it a good adsorbent for treating heavy metals from wastewater and drinking water [5]. Its untreated and modified forms have been reported on efficient removal of many heavy metals such as Cd, Pb, Zn, Cu, Co, and Ni, etc. [26, 30–33].

Based on the best of our knowledge, no study has performed similarly treated rice husk like our simple method to treat Cr^{6+}. Our research aims to modify an available and low-cost material from rice husk to remove Cr^{6+}. Furthermore, testing impact of some driving factors including pH, exposure time, concentration dosage, and temperature, as well as investigating its characterization assays by the Fourier Transform Infrared (FTIR) and Scanning Electron Microscopy (SEM) analysis were performed to display changes between pure and the transformative material. Besides, several important studies including kinetic, isotherm, thermodynamic were carried out to highlight the adsorption mechanism.

Overall, some research's contributions are (1) to utilize the main agricultural waste (rice husk) to become an efficient and environmentally friendly adsorbent to remove Cr^{6+} and potentially with other heavy metals in an acidic environment. (2) It can be a potential material, made by a simple method and it could be an economical adsorbent. (3) Furthermore, the study can be a lesson for future research to apply bio-adsorbent in practice.

2. Materials and Methods

2.1. Materials and Reagents

2.1.1. Preparation for Solutions and Analysis Hexavalent Chromium

All chemicals and reagents used for experiments and analysis are of analytical grade. Hexavalent chromium Cr^{6+} was prepared from potassium dichromate powder ($K_2Cr_2O_7$) in distilled water. The initial pH of the working solution was adjusted by adding NaOH 0.1M and HCl 0.1M, as well as using pH meter (Model 8000). Besides, measurement of residual hexavalent chromium used a calibration curve and 1,5-Diphenylcarbohydrazide method, and was checked by DR2800 at 540 nm wavelength [11].

2.1.2. Preparation for Modifying the Sorbic Acid-treated Rice Husk (SRH)

Raw rice husk was washed with distilled water several times to eliminate impurities and soils, as it can affect color and composition in the solution. Upon washing completion, the material was dried under 80^0C for 6 hours by an oven. Continuously, we took 1 gram of the dried material and soaked with 1M sorbic acid (30 mL) under water in an ultrasonic bath and left for overnight. The next day, the solution was dried and taken the solid, and then kept washing with distilled water until the final pH reached neutral. The residual solid was dried under 80^0C for 6 hours. Finally, it was conserved inside a plastic zip bag to avoid humidity in the atmosphere can reach the material.

2.2. Adsorption Experiments

Batch adsorption studies were performed in black vials containing 40 mL of 100 mgL^{-1} synthetic hexavalent chromium and the amount of concentration dosage 4 g/L under 120 rpm stirring speed for days. Effects of contact time, pH, concentration dosage, and temperature were investigated. After completing the experiments, residual SRH concentrations were measured by using 1.5-Diphenylcarbonhydrazide method with checking by DR2800 at 540 nm wavelength. The percentage for removal Cr^{6+} is calculated as follows (1) [20]:

$$\%adsorption = \frac{C_0 - C_e}{C_0} \text{X} 100\% \qquad (1)$$

C0 and C_e are the initial and equilibrium concentrations of Cr^{6+} in the solution, respectively.

The amount of metal ion (q_t at time t) adsorbed per unit mass of the adsorbent (M) was computed by using the following (2) [23,34]:

$$q_t = \frac{C_0 - C_t}{M} \text{X} V \qquad (2)$$

In which, C_t denotes the concentration (mg/L) of Cr^{6+} at time t and the initial volume of Cr^{6+} stands for V in liter

with M is the mass of adsorbent in gram.

Similarly, the adsorption capacity (q_e) at equilibrium was determined using the mass balance (3) [35]:

$$q_e = \frac{C_0 - C_e}{M} XV \quad (3)$$

3. Results and Discussion

3.1. Fourier Transform Infrared of Adsorbents (FTIR)

Figure 1 shows the FTIR spectra of native rice husk and SRH. The measuring range was detected from 400-4500 cm^{-1}. The plot between the scale of transmission percentages (y-axis) and wavelengths representing x-axis, two curves show the difference between original material (green line) and modified adsorbent (red line) (Figure 1).

In general, the vibrational changes in the functional groups in the adsorbent will determine the adsorption capacity for each material. The peak being around 780-790 cm^{-1} displays the Si-O bond in cellulose [36]. The stretch C-O in hemicellulose and cellulose is presented at 1056 cm^{-1} and 1357 cm^{-1}, respectively [37]. The peaks 1246 cm^{-1} and 1512 cm^{-1} are observed the C=C stretching of guaiacyl rings in lignin, which decreased the intensity of transmission [38].

For comparison, the modified rice husk by sorbic acid appeared some new peaks at 2924 cm^{-1} and 3434 cm^{-1}, they sequentially describe the stretching frequency of the C-H and OH- functional groups, respectively [39]. As well as, the presence of the strong band at 1620 cm^{-1} in the adsorbent determines the stretching vibration of the functional groups (COO-) [40]. These new peaks can predict the adsorption capacity will significantly enhance.

3.2. Scanning Electron Microscopy (SEM) Result

SEM is a helpful method for examining the surface structure and morphological features of materials [41]. Hence, this analysis was applied to determine the differences between raw and modified rice husk (Figure 2, Figure 3). Figure 2 indicates the surface of raw rice husk with parameters is X1000 and 10 µm for magnification and specific scale, respectively. It shows that the pure rice husk has a smooth surface and some small pieces on the surface. It indicates that after modifying by physical processes include washing and milling, it was slightly damaged on its surface. Furthermore, many cones and needle-like the epidermis between the two lines of the frame are observed. This structure makes the rice husk a good adsorbent after being transformed, which is more beneficial for the adsorption of metal ions.

SRH surface was observed at various conditions that comprise X1.000 magnification with 10µm scale (Figure 3a) and X30.000 magnification with 100nm scale (Figure 3b) to determine the significant change compared with raw rice husk surface. It is easy to realize that the shield of raw rice husk was opened dramatically because the cones on the surface could not be observed. These were replaced by a large number of small holes (Figure 3a), as well as many layers showed up on the rough surface with nano-scale pores (Figure 3b). These may be one of the major reasons explaining predictably the adsorption enhancement.

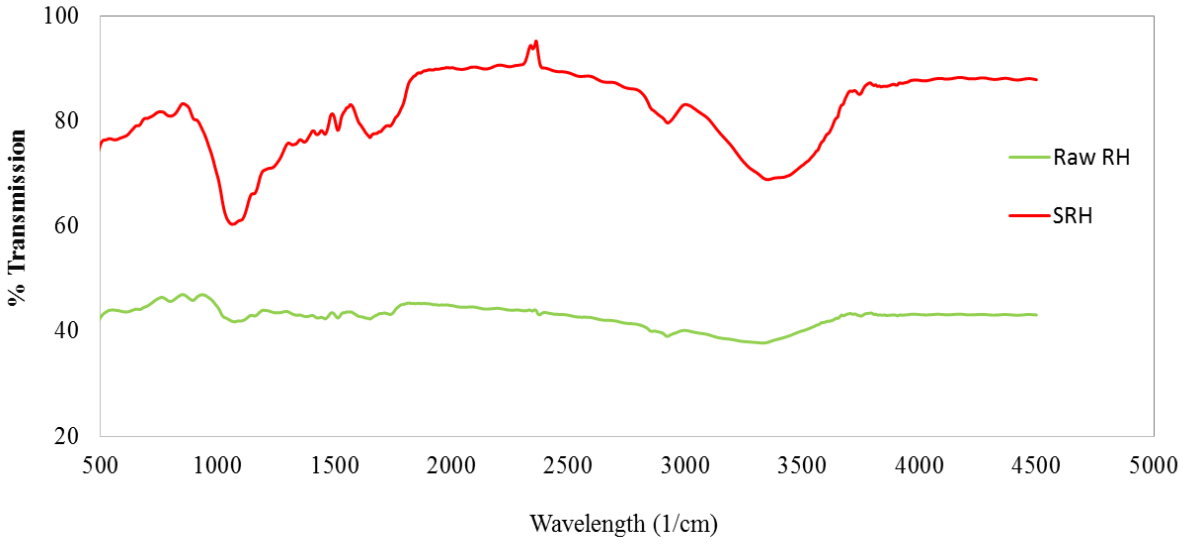


Figure 1. FTIR spectra of raw rice husk (RRH) and sorbic acid treated rice husk (SRH)

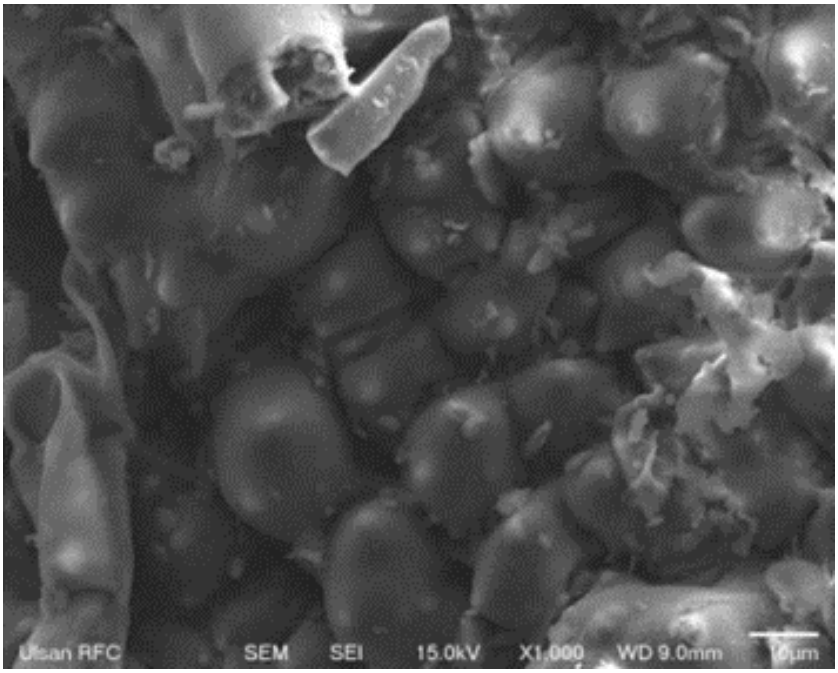
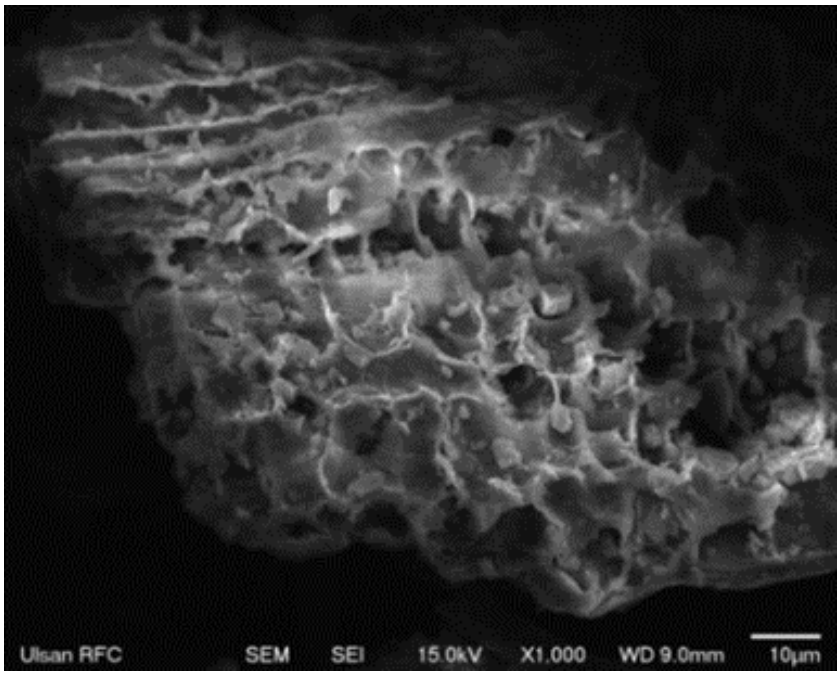
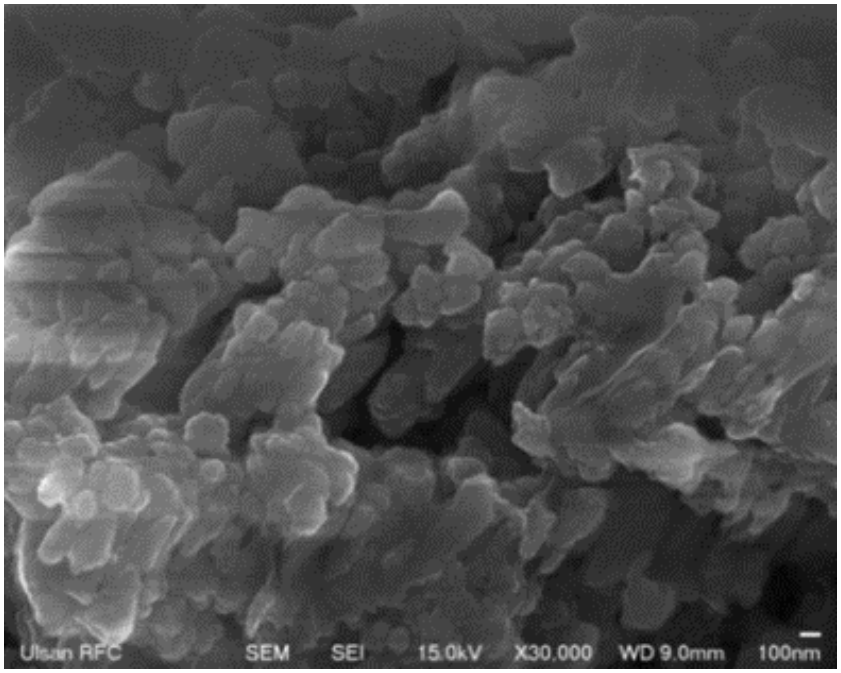


Figure 2. Scanning electronic micrograph of raw rice husk

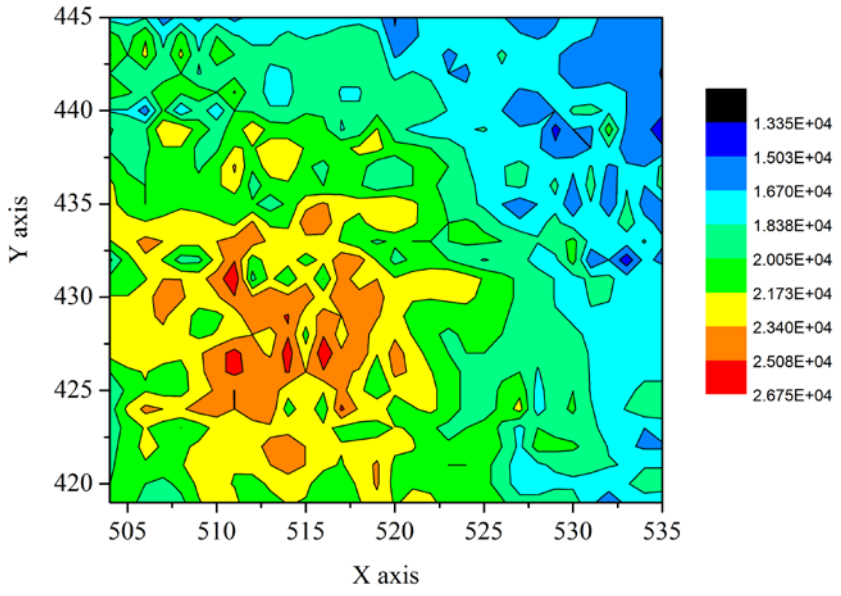


(a)



(b)

Figure 3. **(a)** Scanning electron micrograph of sorbic acid treated rice husk (SRH) at 10µm **(b)** Scanning electron micrograph of sorbic acid treated rice husk (SRH) at 100nm



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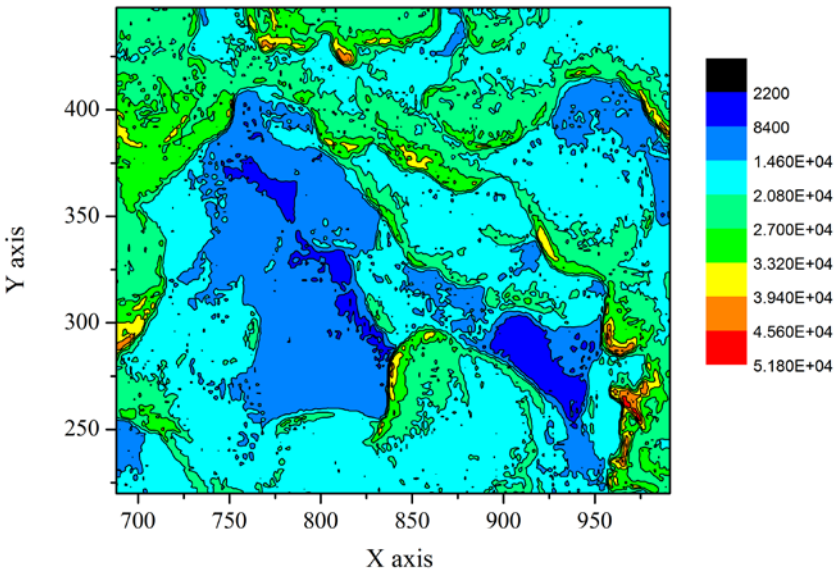


(b)

Figure 4. **(a)** Rebuilt surface of raw rice husk **(b)** SRH surface by matrix on OriginLab

In addition, we also performed the rebuilt contour images for both materials that are exhibited in Figure 4. For raw rice husk, several small holes were hardly found – presenting by black areas in Figure 4a. Besides, the special original structure of raw rice husk is represented by tiny cones, it is exhibited under red color with the relative height 2.875E+04 by following the color scale.

For the SRH contour image, the original surface of raw rice husk was dramatically changed under the physical-chemical processes. Especially, the red areas show peaks of cones these were remarkably decreased – indicating that the shield of rice husk was totally opened (Figure 4b). This image shows that large areas of tiny and deep holes were created and replaced the cones, they are observed under 2200 to 8400 by following the color scale in Figure 4b. According to the color scales between raw and modified materials, the scale of treated rice husk was significantly higher approximately 2 times than raw rice husk color scale. It is good evidence to explain the formation of deep holes in SRH.

3.3. Kinetic Studies

3.3.1. Effect of pH on Removal Cr^{6+} by SRH

According to the Pourbaix diagram for chromium in the aqueous solution (Figure 5), when pH is around 1-2, it can be observed that chromium form is dominated by H_2CrO_4, which is a strong acid [42]. In the solution, an interaction between proton ions and Cr^{6+} could occur before the reaction between Cr^{6+} and the protonated surface of the SRH [43].

pH from 2 to 6.5, increasing pH that leads the uptake rate of Cr^{6+} is rapidly decreased due to chromate anions ($HCrO_4^-$) is decreasingly dominated in the solution. Hence, when the pH is lower the uptake rate is more efficient compared with higher pH. The maximum removal of Cr^{6+} could be observed at pH 2 (Figure 6). It could be explained by protonated and more positively charged on the surface of the adsorbent; it attracts negatively charged from $HCrO_4^-$.

On the other hand, at low pH (1-3), the acidic system is exclusive in the solution and surface adsorbent, so the positively charged is performed by the reaction between oxo groups (C_xO) of the adsorbent and H^+ protons by following equation [44, 45]:

$$C_xO + H^+ \leftrightarrow \{C_xOH\}^+$$

In which, dominant form of Cr^{6+} is $HCrO_4^-$ that reacts with this group to make a complex formation by the equation [44,46]: $\{CxOH\}^+ + HCrO_4^- \leftrightarrow Cx(OH)(OCrO_3H)$

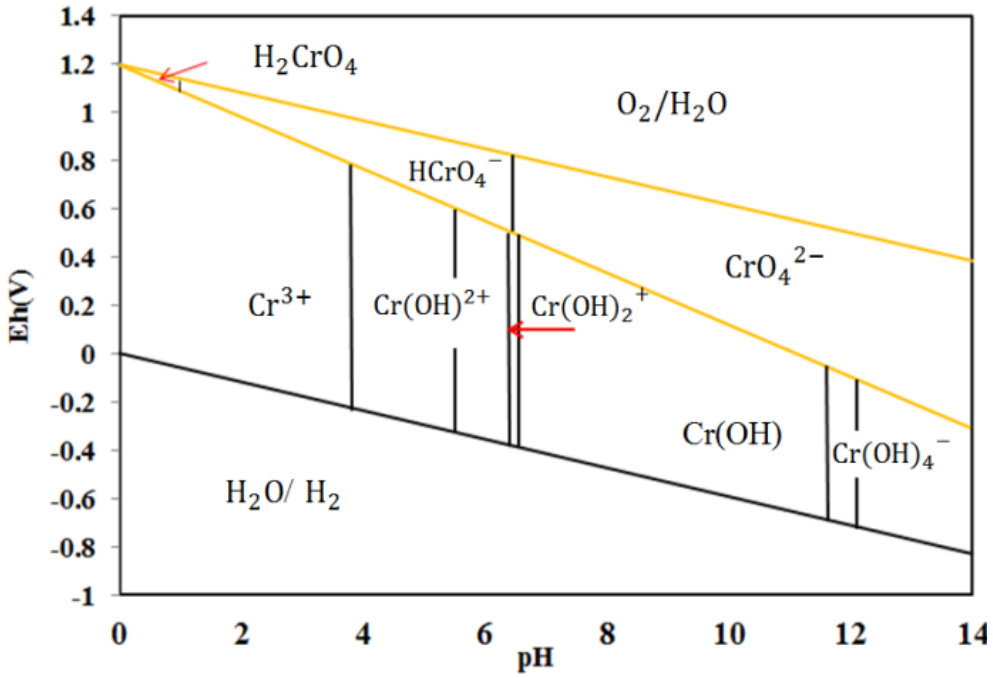


Figure 5. The Pourbaix revised diagram for chromium in aqueous solution

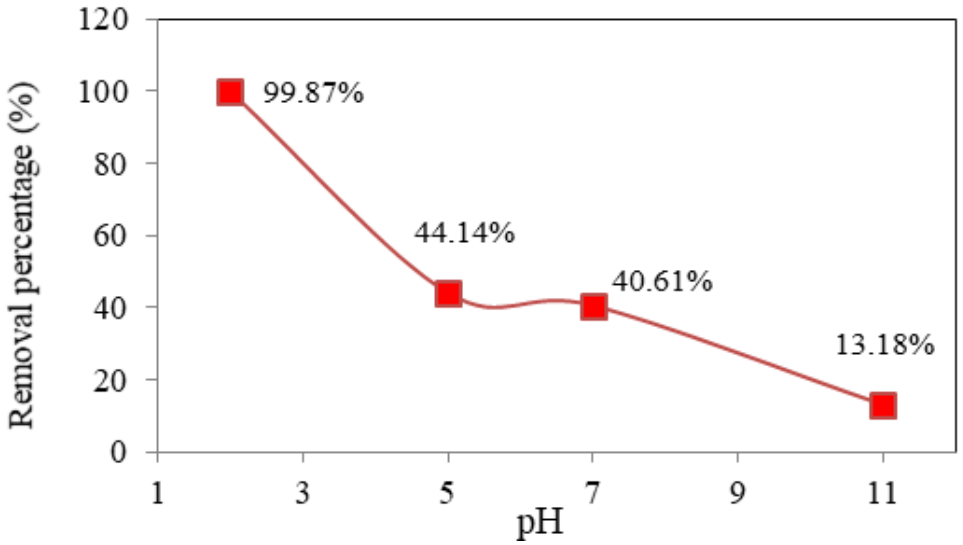


Figure 6. Effect of pH on Cr^{6+} removal. Experimental conditions: initial Cr^{6+} concentration was 100 mg/L with various pH including 2, 5, 7, and 11; concentration dosage: 4 g/L; shaking speed: 120 rpm; and temperature: 30^0C

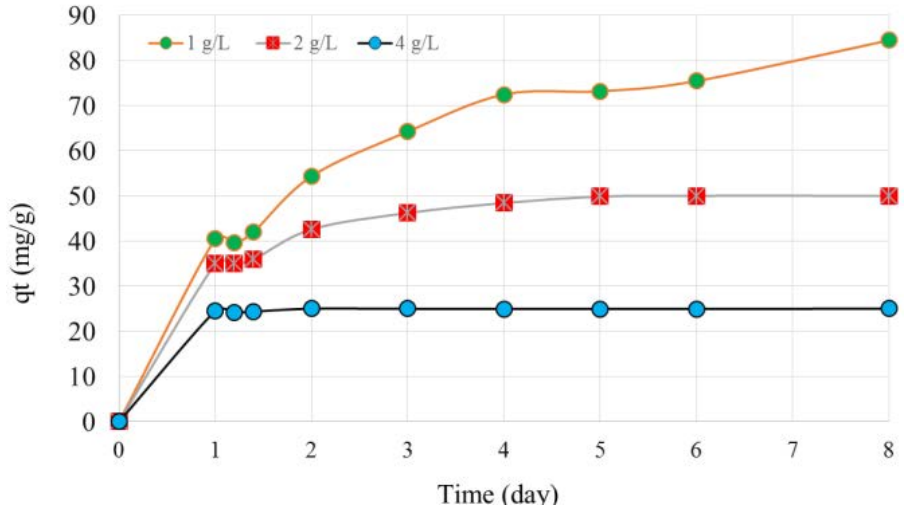


Figure 7. Effect of contact time on Cr^{6+} removal on sorbic acid treated rice husk. Experimental conditions: initial Cr^{6+} concentration was 100 mg/L with optimal pH 2; material ratio: 1, 2, and 4 g/L; shaking speed: 120 rpm; and temperature: 30^0C

At higher pH (>6.5) the form of CrO_4^{2-} is mainly in the solution. The protonated ions are replaced by hydroxyl groups (OH^-) when increasing pH. It is also predicted that effect of pH is influent on the growth of electric double layer on adsorbents. Its polar surface can be strongly changed from positively to negatively charge by changing pH [47]. Basically, the efficient adsorption significantly declines in the stage because the competition on the adsorbent between OH^- and CrO_4^{2-} in the solution. It was reported in some relevant studies [48–50]. Hence, pH 2 was chosen as the optimal value for next studies.

3.3.2. Effect of Contact Time and Concentration Dosage on Cr^{6+} Removal

The effects of contact time and concentration dosage are shown in Figure 7. It indicates that Cr^{6+} adsorption rate was quickly increased for the first 1 day and relatively reached the plateau around 4 days. After that time the adsorption rate was slightly increased on the material. Established equilibrium was taken a long time, it can be explained by the adsorption process that is dominated by diffusion-controlled by physisorption [51].

The percentage removal of Cr^{6+} was increased with increasing concentration dosage. It may be more concentration dosage attributes more surface area for capable approaches between metal ions and surface of the adsorbent [52]. From 1 to 4 g/L concentration dosage the uptake rate increased 84 to 99.9 %, respectively.

Table 1. Adsorption capacity of SRH at different concentration dosage

Adsorbent dose (g/L)	(q_t, mg/g)
1	84
2	50
4	25

In contrast, For SRH adsorption efficiency was declined from 84 to 25 mg/g, respectively (Table 1). This phenomenon may be owing to the overlap of adsorption sites due to overcrowding of adsorbed particles [53].

3.4. Adsorption Isotherm

3.4.1. Langmuir and Freundlich Models

The Langmuir adsorption isotherm: The Langmuir isotherm assumes that adsorption occurs on uniform surfaces and monolayer adsorption. The plot between C_e and C_e/q_e shows the linearized form of the model, which is represented by the following (4) [54, 55].

$$\frac{C_e}{q_e} = \frac{1}{q_{\max}}\frac{1}{K_L} + \frac{1}{q_{\max}}C_e \quad (4)$$

Where, q_{max} denotes the maximum metal ions absorption per unit mass of adsorbent (mg/g), b is the Langmuir (L/mg) constant proportional to the heat and related adsorption intensity.

Freundlich isotherm is an empirical equation used to describe heterogeneous systems. The linearized form of the Freundlich isothermal (5):

$$\log q_e = \log K_f + \frac{1}{n}\log C_e \quad (5)$$

In which, the Freundlich constants K_f and 1/n are the Freundlich constants related to the adsorption capacity and sorption intensity of sorbent, respectively, these are calculated from the intercept and slope of the plot of $Logq_e$ versus $LogC_e$ for the adsorption of Cr^{6+} ions onto materials.

Major models that include Langmuir and Freundlich were performed to understand the behavior of the adsorption process. The linear for each model is shown in Figure 8. Its parameters such as correlation coefficient value were calculated by (4) and (5).

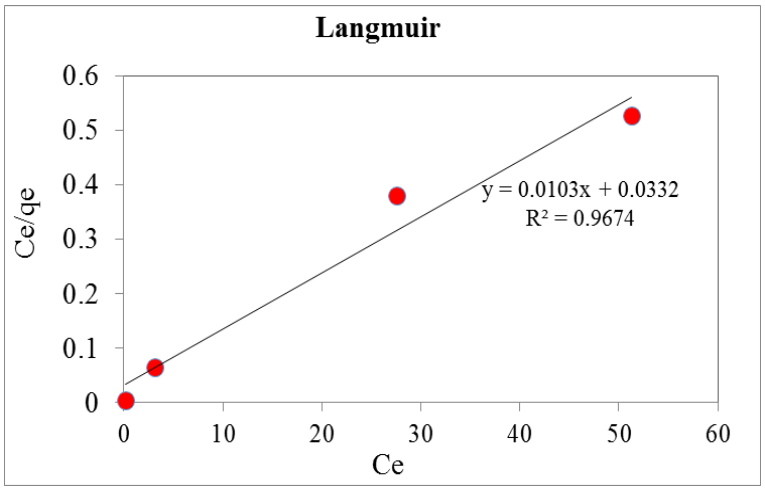
Table 2 shows the parameters and correlation coefficient (R^2), which provides a satisfactory for each fitting model. Langmuir and Freundlich models have acceptable coefficient correlations 0.9674 and 0.9873, respectively. The adsorption capacity at equilibrium, q_{max} is 97.09 mg/g, which was reported by Langmuir model. Besides, the separation factor (R_L) in Langmuir model is evaluated by

$R_L = 1/(1+bC_0) = 0.03125$ ($0<R_L<1$) [56], so it is an evidence for the favorable adsorption [57]. It also determines that the monolayer adsorption on the homogeneous adsorbent surface occurred on the system.

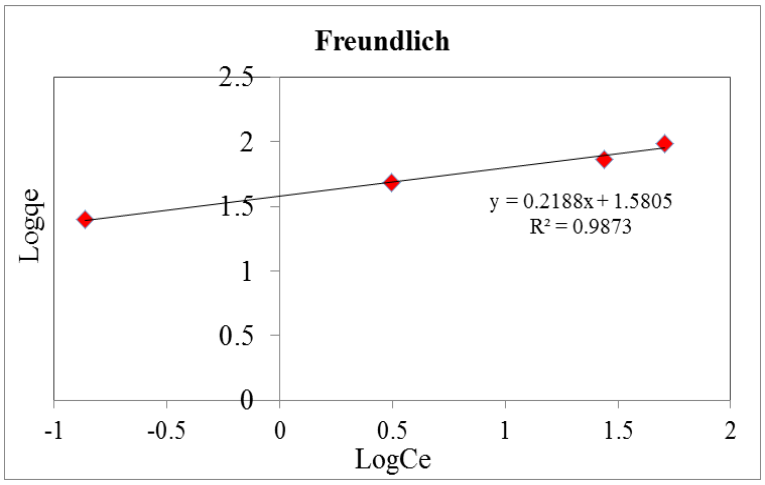
The plot between $LogC_e$ and $Logq_e$ represents Freundlich model, which is shown in Figure 8. The empirical model was also fitted well with $R^2 = 0.9873$. Furthermore, the sorption intensity of sorbent value (n) in Freundlich is over 1, the adsorption capacity is K_f 38.06 $mg/g)(mg/L)^{-1/n}$ [58]. The reason might come from the non-uniform surface of this adsorbent. The presence of multilayer adsorption was suitable for heterogeneous adsorbent on the system. Based on both models, they denote that uptake Cr^{6+} was occurred on homogeneous and heterogeneous surface with layer by layer. In addition, physisorption mechanism was exclusively to remove Cr^{6+} by electrostatic attraction.

Table 2. Langmuir and Freundlich parameters for removal Cr^{6+} by SRH

Langmuir isotherm			**Freudlich isotherm**		
q_{max} (mg/g)	b (L/m)	R^2	K_f $((mg/g)(mg/L)^{-1/n})$	n	R^2
97.09	0.31	0.967	38.06	4.57	0.98



(a)



(b)

Figure 8. Adsorption isotherm: **(a)** Langmuir **(b)** Freundlich models for removal Cr^{6+} by SRH

Comparison adsorption capacities among various materials to removal Cr^{6+}, these have been successfully studied at pH 2 (Table 3), it denotes that SRH is a potential material for removal of Cr^{6+} with adsorption capacity that is 97.09 mg/g evaluated by Langmuir. Because the model reports the value is close with experimental data, as well as the coefficient correlation R^2 is acceptable for the study (R^2 = 0.9674).

3.5. Kinetic Adsorption

3.5.1. Pseudo first and second model

To determine the adsorption kinetic mechanism of Cr^{6+}, the experimental data are analyzed by Lagergren Pseudo-first and second-order kinetic models as expressed by the following (6) and (7) [62].

$$Log(q_e - q_t) = Logq_e - \frac{K_1 t}{2.303} \quad (6)$$

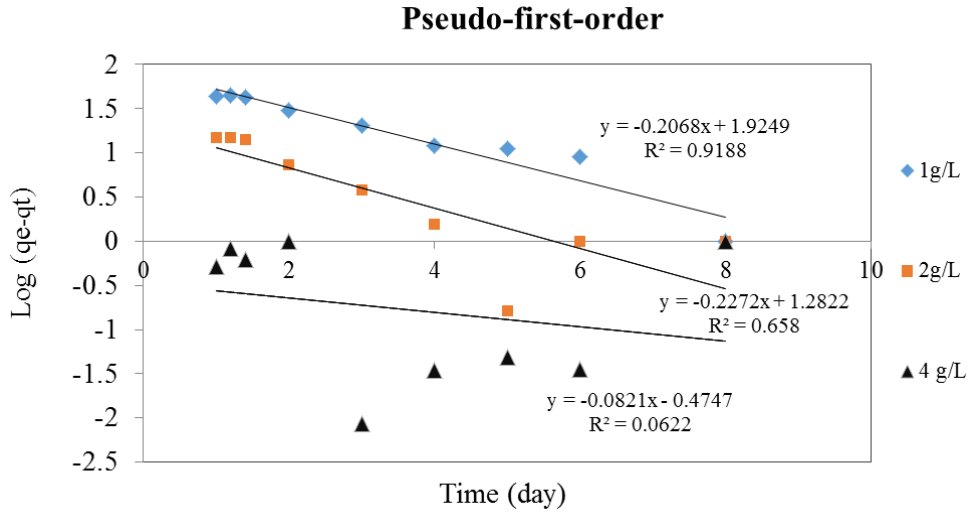
Pseudo-second-order kinetic model is based on empirical information on solid phase adsorption and is used to heterogeneous systems and the adsorption capacity is proportional to the number of active sites on the sorbent.

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \quad (7)$$

Where, is the equilibrium adsorption capacity (mg/g), q_t is the adsorption capacity at time t (mg/g), K_1 (day^{-1}), K_2 (g/mg.day) are the adsorption rate constants.

Table 3. Comparison adsorption capacities of different adsorbents for hexavalent chromium

Adsorbent	q_{max} (mg/g)	pH	Model applied to calculated adsorption capacity	Reference
Raw dolomite	10.01	2	Langmuir	[59]
Boiled rice husk	8.5	2	Langmuir	[60]
Formaldehyde treated rice husk	10.4	2	Langmuir	[60]
Peanut shell	16.26	2	Langmuir	[35]
Sulfonated lignite	27.87	2	Langmuir	[34]
Activated olive bagasse	88.59	2	Langmuir	[61]
SRH	97.09	2	Langmuir	The study



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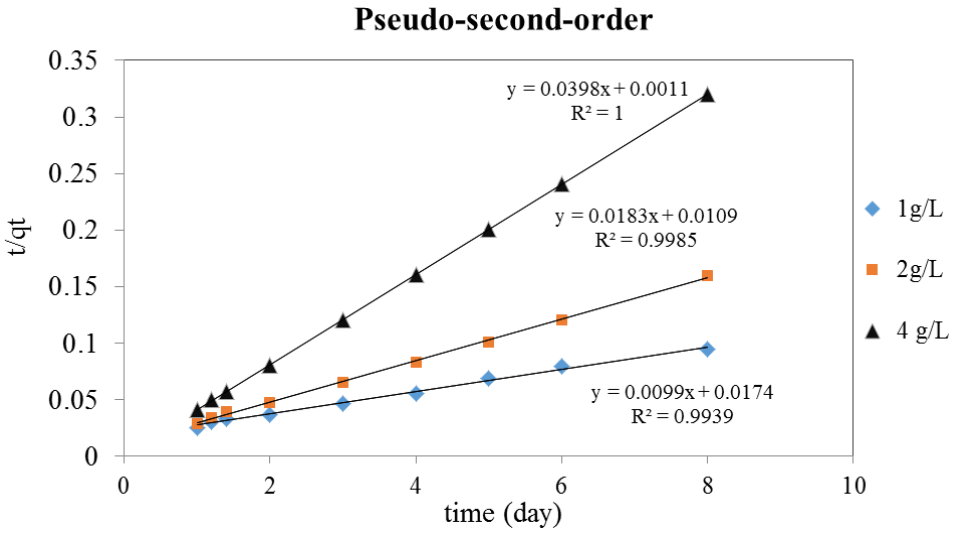

(b)

Figure 9. **(a)** Pseudo-first and **(b)** second order models for removal Cr^{6+} by SRH

Table 4. Pseudo-first and second parameters for removal Cr^{6+} by SRH

Adsorbent	Pseudo-first-order constants			Pseudo-second-order constants		
	q_e (mg/g)	K_1 (day^{-1})	R^2	q_e (mg/g)	K_2 (g/mg.day)	R^2
At 1g/L	84.12	0.47	0.9188	101.01	0.005	0.9939
At 2 g/L	19.15	0.52	0.658	54.64	0.03	0.9985
At 4g/L	0.33	0.18	0.0622	25.12	1.44	1

Both of plots for Pseudo-first and second models at various concentration dosages are given in Figure 9. The correlation coefficient value (R^2) for each model is computed by (6) and (7) and shown in Table 4.

For Pseudo-first-order, coefficient correlation value at each concentration dosage study is relatively low from 0.0622 to 0.9188. Thus, Pseudo-first order is unfavorable for the study. For comparison with Pseudo-second order, R^2 values are higher than Pseudo-first-order values (0.9939, 0.9985, and 1 at 1, 2, and 4 g/L concentration dosages, respectively) (Table 4). It indicates that Pseudo-second-order model is well fitted. It is evidence that chemisorption occurred between Cr^{6+} and the active sites on the adsorbent [63].

3.6. Adsorption Thermodynamics

The thermodynamic study was carried out under initial Cr^{6+} concentration that was 100 mg/L, it was treated by 2 g/L SRH for 2 days under 283, 293, and 303K with 120 rpm for stirring speed. The study presents the adsorption process, spontaneously and feasibly. Based on the thermodynamic parameters include Gibbs free energy (ΔG^0), enthalpy (ΔH^0), and entropy (ΔS^0) are shown from the following (8) and (9) [64].

$$LnK_c = \frac{-\Delta H^0}{RT} + \frac{\Delta S^0}{R} \quad (8)$$

Where, K_c is computed by the ration between q_e and C_e

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (9)$$

Where, R (8.314 J/mol K) is the gas constant, T is temperature (K). The thermodynamic parameters of both adsorbents are given in Table 5.

Table 5. Thermodynamic parameters for Cr^{6+} adsorption by SRH

T (K)	ΔG^0 (kJ/mol)	ΔH^0 (kJ/mol)	ΔS^0 (kJ/(molK))
283	-1.558	45.94	0.1678
293	-3.237		
303	-4.915		

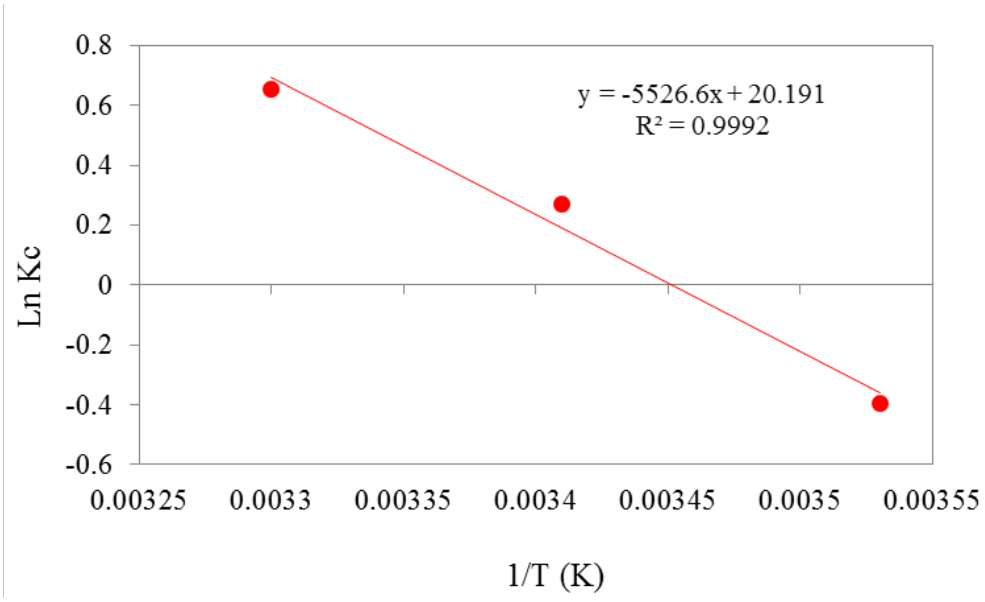

Figure 10. Plot of LnK_c versus 1/T for adsorption Cr^{6+} by SRH

The curve represents the relationship between LnK_c and 1/T is shown in Figure 10. Besides, the parameters of thermodynamic study are given in Table 5. ΔH^0 is 45.94 kJ/mol, ΔS^0 0.1678 kJ/molK (Table 5). The positive enthalpy for the adsorbent confirms the endothermic nature of the Cr^{6+} adsorption. Similarly, entropy value is a positive value which indicates that the adsorption process is randomness [65]. Through the free energy values for all of temperatures are negative, it determines the adsorption process is favorably spontaneous [49, 66].

4. Conclusions

(1) Because it is often used in the food additive business and is thus benign to the environment and human health within the permitted standard concentration, the authors of this study chose to utilize sorbic acid as their friendly acid. Citric acid, which may entirely replace sorbic acid when we do not have it, and vitamin C (ascorbic acid) were also taken into consideration by the author for this study. This allows us flexibility when actually changing the material. The aforementioned acids in particular are readily available and rather well-known.

(2) Research has demonstrated that the transition between the original material and the post-modified material may be altered using SEM and FTIR technologies.

(3) The findings demonstrate that several new functional groups and surface pores emerge on the changed material, which facilitates Cr^{6+} adsorption. Compared to the parent material, the adsorption capacity is substantially larger.

(4) At pH = 2, contact duration = 4 days, and material dose = 4 g/L, it is estimated that 99.9 % of the initial 100 mg/L Cr^{6+} was eliminated.

(5) The Langmuir model can accurately describe the 97.09 mg/g Cr^{6+} adsorption capacity of SRH by the use of adsorption capacity assessment models such Freundlich, Pseudo first and second order, and Langmuir. As a result, it can be shown that the removal of Cr^{6+} occurs spontaneously and adsorbs through a variety of intricate processes. Some models have R2 values that are close to 1, which is also true. Adsorption can occur in monolayers or several layers. In order to strengthen the capacity to remove Cr^{6+} and fully understand the adsorption process, this work may be expanded.

(6) Because of the materials' inherent properties, this study will serve as the basis for further research aimed at enhancing Cr^{6+} adsorption by substituting additional materials as bagasse, maize stalks, banana stalks, water hyacinth, etc. The hollow body structure of this substance will lead to the development of new, modified materials with even greater adsorption capacities. This is true in particular for the ingredients used to make the rice husks that were the subject of this investigation because of how widely distributed and abundant they are internationally.

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