


Research Article

High-Efficiency Adsorption of Hexavalent Chromium from Aqueous Solution by *Samanea saman* Activated Carbon

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Heavy metal wastewater pollution has become an environmental and industrial challenge worldwide. Hexavalent chromium (Cr(VI)) is one of the most common forms of chromium metal. Hexavalent chromium pollution is a concern because it was hazardous and can accumulate in the tissues of living organisms and the environment. The adsorption method using activated carbon can be one of the methods to treat hexavalent chromium waste. This study selected *Samanea saman* as the activated carbon because it contains hemicellulose, lignocellulose, and lignin, which are the requirements for an excellent activated carbon. The study's objective is to analyze *Samanea saman* activated carbon (SSAC) to remove hexavalent chromium, measure the adsorption capacity, and determine the appropriate type of adsorption isotherm layer based on the maximum R^2 and minimum χ^2 values. The process of making activated carbon was activated using K_2CO_3 through a pyrolysis process and using batch adsorption. The SEM results as characterization of SSAC depicted that the high pore was well developed. The optimal conditions for *Samanea saman* indicated high efficiency toward hexavalent chromium ions within the following process parameters; pH value 5, adsorbent dosage 5 g, and initial concentration 20 mg/L. The findings demonstrate that SSAC leads to the removal efficiency of hexavalent chromium being 99.90%, with the greatest adsorption capacity of 0.8949 mg/g. Based on the maximum R^2 and minimum χ^2 values, the most suitable adsorption isotherm model in SSAC was the Freundlich isotherm existing in the monolayer ($R^2 = 0.999$). The experimental results demonstrated that adsorption of Cr(VI) was well performed by SSAC. Thus, the SSAC material is an appropriate adsorbent for the removal of hexavalent chromium in the water and has the potential to be industrial applied.

1. Introduction

Industrial activity improvement will increase wastewater production [1]. One of the wastewater contains heavy metals [2]. The crucial role of metals in the environment is to maintain the functionality of the biochemical and physiological of living organisms in low concentrations. However, it is dan-

gerous when the metal concentration exceeds a certain threshold [3, 4]. The wastewater must be treated before being discharged into the aquatic environment to comply with the quality standards required not to cause pollution. Pollution by industrial wastewater is a dominant environmental problem. Wastewater without treatment will negatively impact the waters [5]. Factor the causes of low

quality in the wastewater industry is the presence of the content of heavy metals contained in the wastewater, one of which is chromium (Cr).

Chromium (Cr) is a natural metal found in the earth's crust-shaped chromite ore. Cr has several oxidations, namely, Cr^{2+} — Cr^{6+} . Cr^{3+} and Cr^{6+} are formation Cr common and stable. Naturally, Cr is found in all environmental components, such as water, air, and soil but few in the amount [6]. Cr^{6+} is often used in waste industry textile, electroplating, mining, leather tanning, fertilizer, cement, and photography [7]. Pollution by Cr^{6+} is a concern because it can be accumulated in the tissues of living organisms [8]. Hexavalent chromium is one such pollutant that has sparked great interest among researchers because of its recognized toxicity in the environment and human health [9].

Various treatment methods for removing metal ions in aqueous solution and wastewater are electro dialysis, ion exchange, reduction, evaporation, electrochemical, chemical precipitation, reverse osmosis, solvent extraction membrane process, inorganic sorbent, and adsorption [10–14]. Most of the methods with a shortage of capital and operating costs are high or problems in the disposal of residues [15]. The adsorption method is one of the methods of processing cost-effective, efficient, and effective treatment methods in removing Cr^{6+} [16]. Adsorption is considered a separation process that supports the removal of pollutants with low concentrations in drinking water, wastewater, and aqueous solutions [17]. The usefulness of activated carbon for wastewater treatment by adsorption method was elevating. The increasing demand for activated carbon requires newly capable and readily available alternatives.

In general, lignocellulosic materials are considered the rawest material for the standard preparation of activated carbon [18]. The lignocellulosic composition in biomass varies between lignin, hemicellulose, and cellulose [19]. Hemicellulose, lignocellulose, and lignin are essential compounds in biomass from agriculture as materials for the common activated carbon. Lignocellulose materials sourced from agricultural wastes have been recognized as the most prevalent feedstock for the synthesis of activated carbon [18]. It was known that compound cellulose of material is very dominant because they have a good potential in the adsorption to remove heavy metals [19].

Samanea saman (Trembesi) is one of the green plants that are often found on the roadside. *S. saman* has spread to the islands of Samoa, Fiji, Guam, Papua New Guinea, Mainland Micronesia, and Indonesia. *S. saman* is classified as a fast-growing plant [20]. *S. saman* is a type of fruit that is rarely consumed. The shaped pods are straight, slightly curved, and blackish brown.

The SSAC was chosen as an adsorbent with consideration of previous studies [21–23]. In this study, the *Cassia fistula* (golden shower) activated carbon was considered a preliminary study for the preparation of the SSAC. SSAC was chosen because it is still in one taxonomy in the same family with golden shower, i.e., Fabaceae. *S. saman* is one of the new alternative potentials of activated carbon that can be used. In the present study, SSAC was synthesized and applied for the adsorption hexavalent chromium from

an aqueous solution. The adsorption process of hexavalent chromium was investigated in batch experiment under varying operation conditions (initial concentration, pH, and adsorbent dose). Finally, we propose a simple and effective approach for using potential *Samanea saman* as activated carbon material in hexavalent chromium adsorption.

2. Methodology

2.1. Materials and Chemical. Sodium hydroxide (NaOH), hydrochloric acid (HCl), and potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) were purchased from Merck Chemical Company. All solutions were prepared from the ultrapure water system. The pH meter from Puchun was used to measure the pH of solutions. Cr(VI) stock solution of 1000 mg/L in ultrapure water was prepared using $\text{K}_2\text{Cr}_2\text{O}_7$. A stock solution of Cr^{6+} was prepared by dissolving 2,828 g of potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) with distilled water as much as 1000 mL. The stock solution was used to further the preparation of the experiment using dilution according to the initial concentration of Cr^{6+} metal desired.

2.2. SSAC Preparation. *S. saman* was collected from the front yard of the university. *S. saman* fruit is sorted to separate between the peel and seeds. The peel of the *S. saman* fruit was cleaned with tap water and rinsed with distilled water to remove impurities that were still attached to the peel of the *S. saman*. After that, *S. saman* peel was dried in the oven at a temperature of 80°C for 24 hours. The dried *S. saman* was grounded and sieved to obtain a particle size of 0.250 mm.

In a porcelain crucible, the powdered *S. saman* was inserted, and the crucible was covered with a lid. The crucible was then placed in a muffle furnace—Thermolyne FB 1310 M-33 in a limited oxygen atmosphere for 2 h. The pyrolysis temperature ranged 800°C for 4 h [21]. After carbonization, the *S. saman* samples were allowed to cool down to room temperature in the furnace. The resulting *S. saman* was grinded and passed through the mesh screen. To remove ash and contaminants from *S. saman* samples, they were washed in deionized water and dried for 24 hours at 80°C [24]. *S. saman* peels were activated through a chemical process with K_2CO_3 . The precursors (SSAC) were submerged in K_2CO_3 at a mass ratio of 3 : 1, then pyrolyzed at 800°C for 4 hours. The samples were carefully rinsed with 0.1 M HCl after carbonization to dissolve ash and inorganic salts. Finally, the samples were washed with deionized distilled water until the pH of the filtrates was constant. After that, the samples were dried and sieved before being kept.

Activation with K_2CO_3 was carried out to increase the adsorption of hexavalent chromium. The activation aims to decompose mineral salts such as metal Cr^{6+} to the adsorbent. The reduction of mineral salts is characterized by the formation of COOH and OH functional groups on the adsorbent so that more Cr^{6+} metals will be adsorbed. K_2CO_3 was chosen as the activator because it presented the highest surface area of almost 2,000 m^2/g when compared to adsorbents activated using KOH (about 1,400 m^2/g), NaOH (1,200 m^2/g), ZnCl_2 (1,000 m^2/g), Na_2CO_3 (800 m^2/g)

g), and H_3PO_4 (700 m^2/g) [18]. The pyrolysis processes at a temperature of 800°C for 4 hours to get the SSAC. The purpose of pyrolysis is to release volatile matter found in biomass. It was known that the content of volatile matter contained in biomass is quite high [25].

2.3. Batch Adsorption Experiments. The adsorption process in this study used a batch system. The batch system is an adsorption process in which the adsorbent is mixed with a fixed amount of solution for a specific time and then observed. The stages of the adsorption process begin by inserting the solution into an Erlenmeyer flask with a volume of 150 ml concentration has been determined. The pH of the solution was adjusted with NaOH or HCl solution. After obtaining the optimum pH conditions, the solution varied with the concentration of the wastewater of 5 mg/L, 10 mg/L, 20 mg/L, and 30 mg/L. The samples were stirred for 180 minutes at a speed of 120 rpm. Then, the sample was separated between the filtrate with the adsorbent. The filtrate is what will be analyzed to determine whether heavy metal concentrations are contained in the solution that has been adsorbed. The concentration value test will be carried out using a spectrophotometric tool using the 2017 APHA 4500 Cr B method.

2.4. Scanning Electron Microscopy. SEM (HITACHI FLEX-SEM 1000) was employed to investigate the surface morphology of the adsorbent. It also provides information about structure, i.e., porous adsorbent.

2.5. Statistical Analysis. All experiments were carried out in duplicate. The adsorption equilibrium model could be determined based on the value of the linear coefficient of determination (R^2) and supported by the statistical test of nonlinear chi-square (χ^2). The value of R^2 is obtained on the graph of the adsorption isotherm equation and determines the highest near 1. Chi-square (χ^2) value cannot be negative because the nominal variable can be interpreted as not correlating [26]. The purpose of using the chi-square (χ^2) in the determination of the model isotherm adsorption is to validate the appropriate isotherm model because chi-square (χ^2) gives better results in the conclusion of the experimental data on adsorption isotherms [27].

$$\chi^2 = \sum \frac{(q_{e,\text{exp}} - q_{e,\text{cal}})^2}{q_{e,\text{cal}}}, \quad (1)$$

where $q_{e,\text{exp}}$ (mg/g) is the adsorption capacity at equilibrium, and $q_{e,\text{cal}}$ (mg/g) is the adsorption capacity determined from the adsorption model.

3. Results and Discussion

3.1. SSAC Characteristics. Morphological characterization of the adsorbent was carried out using a scanning electron microscope (SEM). SEM analysis aims to determine the surface microstructure of a material. SEM analysis assesses the microstructure of a material, including morphology, texture, crystallographic information, and particle surface composi-

tion. The morphology was observed in the form of shape, size, and arrangement of the particles [28]. The adsorbent used in this SEM analysis is the SSAC adsorbent, which K_2CO_3 activates. The results of the morphological characteristics of the adsorbent by SEM were carried out at a magnification of $10.000\times$.

The ability of the adsorbent to adsorb adsorbate is influenced by the large structure in the internal pores, that is, macropores, mesopores, and micropores. Based on SEM results, the adsorbent SSAC was depicted in Figure 1; the surface morphology of adsorbent SSAC is irregular and heterogeneous. In addition, SSAC also has a structure pore like a sponge. Structure pores like a sponge. The formation of pores well developed of various sizes during the pyrolysis process results from the evaporation of K_2CO_3 . The high surface area of the activated K_2CO_3 expands the pores within easy reach. The previous study reported that pore channels were formed as a result of the chemical activator and heating [9]. Changes in pore shape and volume could be attributed to the activating agent's increased strength [9]. Higher pores affect the adhesion of metals to the adsorbent surface [29]. The formation of pores in the adsorbent during the pyrolysis process has a vital role in increasing the surface area and total pore volume. It is expected to generate a surface area higher than the total pore volume. It was denoted that adsorbents could adsorb Cr(VI) metals. Therefore, it can be concluded that the surface morphology of the adsorbent is highly dependent on the preparation method.

3.2. Effect of pH. One of the crucial parameters is solution pH, which has a significant impact on the adsorption process. The adsorption of Cr(VI) was investigated over the pH range of 3-9 with 15 g of adsorbent put into a solution of Cr(VI) initial concentration of 30 mg/L.

Based on Table 1, effect of pH on adsorption of Cr(VI) using SSAC at pH 3-5 has an increase in the adsorption of metal Cr(VI). The amount of H^+ ions decreases, the carbon surface is ionized by removing H^+ ions, and carbon becomes negative. At pH 7 decreased and pH 9 increased in the adsorption of metal Cr(VI) to the formation of metal hydroxide precipitate. However, the final pH of the results of variations in pH 3, 5, 7, and 9 ranged between 11.95 and 12. Increasing pH to alkaline can decrease heavy metals concentration, when adsorbent is added, heavy metals will react with hydroxide ions to form solid metal hydroxide [30].

As shown in Table 1, the final pH solution is increasing. Protonation was carried out in the acid condition. H^+ ions contained in the adsorbent will be protonated and positively charged, which can react to metals in the form of cations. In the presence of OH^- ions, the adsorbent will be deprotonated and negatively charged, which can respond to metals in the form of cations. Protonation is the addition of a proton (hydrogen cation/ H^+) into a molecule and forms a conjugate acid, while deprotonation removes a proton (hydrogen cation/ H^+) from a molecule and forms a conjugate base. Acidic pH conditions are suitable for the adsorption process, but when the solution is in alkaline conditions will create a hydroxide precipitate so that the adsorption process becomes inhibited [31]. The decrease in pH that occurs will

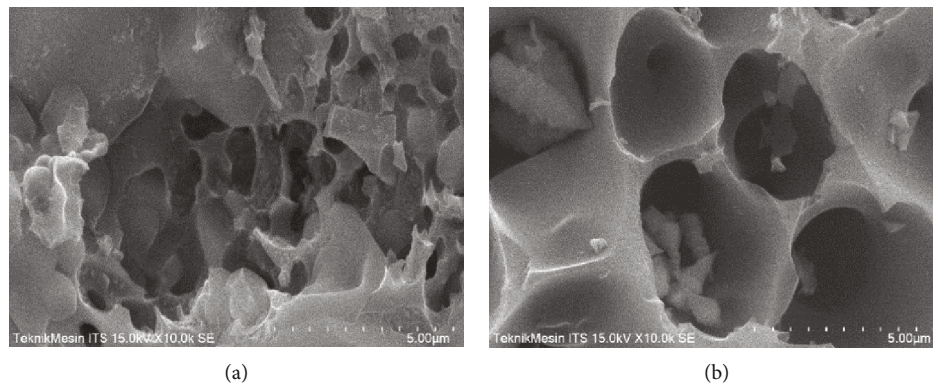


FIGURE 1: Scanning electron micrographs (SEM). (a) SSAC before adsorption. (b) SSAC after adsorption.

TABLE 1: Effect of pH on adsorption of Cr(VI) using SSAC.

Initial concentration of Cr(VI) (mg/L)	Final concentration of Cr(VI) (mg/L)	Initial pH	Final pH
30	0.685	3	11.95
	0.680	5	11.95
	0.890	7	12
	0.663	9	11.95

cause desorption [32]. In contrast, the pH that has increased competition between H^+ and positively charged metal ions will decrease on the carbon surface resulting in low repulsion of Cr^{6+} . The metal will be easily adsorbed into the adsorbent [33].

According to Figure 2, the efficiency of SSAC was achieved by nearly 100%. This is corroborated by an increase in pH following the adsorption process. The previous study reported that the various pH values and concentrations, Cr(VI) can exist in various ionic forms such as chromate (CrO_4^{2-}), hydrogen chromate ($HCrO_4^-$), or dichromate ($Cr_2O_7^{2-}$). At low pH, the hydrolysis process of dichromate ion ($Cr_2O_7^{2-}$) frequently produces $HCrO_4^-$, which then becomes the main Cr(VI) species in acidic circumstances. However, increasing the pH leads the $HCrO_4^-$ equilibrium to shift toward the production of CrO_4^{2-} and $Cr_2O_7^{2-}$ species [9]. At pH range of 2-6, various forms of chromium ions exist in the form such as $Cr_2O_7^{2-}$, $HCrO_4^-$, and $Cr_3O_{10}^{2-}$ coexist, and $HCrO_4^-$ dominates all of them. $HCrO_4^-$ was transformed into CrO_4^{2-} and $Cr_2O_7^{2-}$ types when the pH increased. As a consequence, Cr(VI) adsorption was advantageous in the acidic pH range, indicating that low pH increases H^+ ion concentration and results in a significantly strong electrostatic attraction between positively charged adsorbent surface and chromate ions. In the acidic range, where Cr(VI) was dominant, raising the pH reduced removal adsorption dramatically because $HCrO_4^-$ ions had a higher affinity for H^+ [29, 34].

The result of this study stated that chromium was successfully declined. It denotes that the toxicity would potentially decrease. The increase in pH in the solution can also reduce the solubility of metals in water and can also change the stability of the carbonate form to hydroxide and form a

bond that will precipitate be mud [35]. It can occur caused by the neutralization of the negative charge contained in the surface of the carbon characterized by the increasing concentration of H^+ , so the surface is more active on the carbon. The metal's solubility can be affected by pH. The pH conditions in the adsorption solution will affect the heavy metal adsorption process [31].

Heavy metal species have a specific low solubility to a certain pH. The solubility of Cr^{3+} occurred at pH 8.5 and Zn^{2+} at pH 9.5 [36]. However, after the pH increased from pH 10 to pH 11, it caused hydroxyl ions (OH^-) more so that $Cr(OH)_3$ dissolved [37]. This statement shows that the pH value, which shows the percentage decrease in heavy metals not necessarily have the same percentage decrease in the different types of heavy metals. Some heavy metals are amphoteric. Therefore, the solubility reaches a minimum value at a certain pH [36]. The optimum pH value for the adsorption process of heavy metals is generally different and can be obtained through research conducted in the laboratory. In this study, the optimum pH at pH 5 is with a percentage removal of 97.73%.

3.3. Effect of Initial Concentration. The effect of the initial concentration of Cr(VI) metal was investigated in the various concentrations of 5 to 30 mg/L, pH solution 5, and contact time 180 min. The effect of the initial concentration of Cr(VI) metal is shown in Figure 3; it can be seen that the adsorbent from SSAC can adsorb Cr(VI) with an average total efficiency of 98.09%. Cr(VI) metal with an initial concentration of 30 mg/L can be adsorbed by SSAC, and it is characterized by the obtained efficiency above 90%. It stated that the adsorption capacity of SSAC is well performed in the initial concentration range of this study.

The initial concentration is a major driving force in overcoming the ion mass transfer barrier between the aqueous and solid phases [8, 38–40]. The accessible sites may be occupied at greater concentrations, and subsequent clearance is dependent on the initial concentration [8, 39–41]. When the concentration was increased, there was a rapid increase in adsorption, followed by gradual adsorption until stability was established. This is related to the availability of adsorption sites, which initially leads to enhanced adsorption and then decreases following saturation of the adsorption sites [42]. This is due to increased metal ions competing for

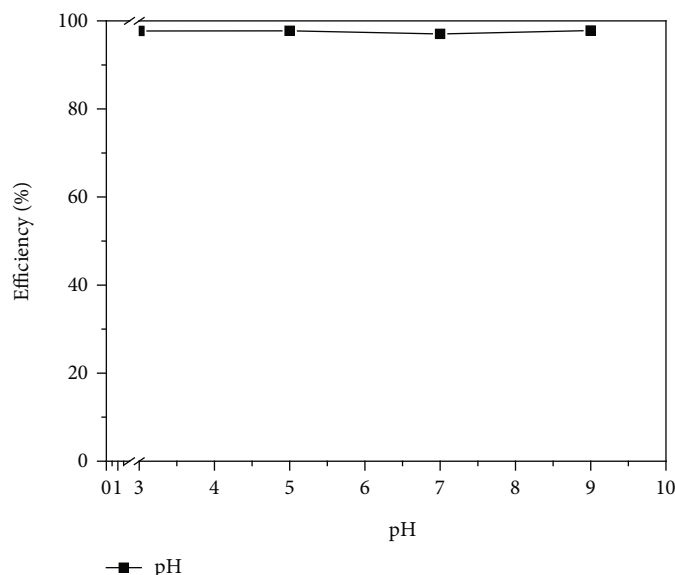


FIGURE 2: Effect of pH on percentage removal of Cr(VI) by SSAC ($C_0 = 30$ mg/L; adsorbent dose 15 g; agitation speed = 120 rpm; time = 180 minutes).

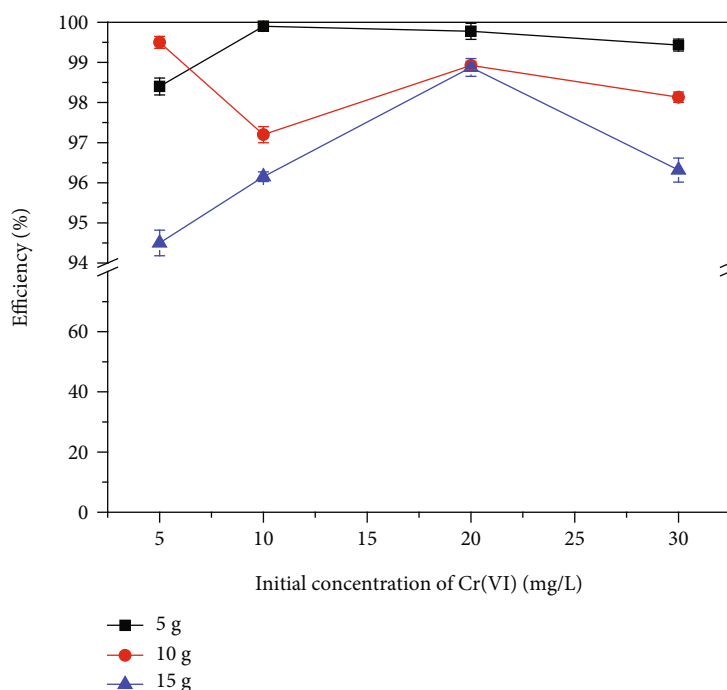


FIGURE 3: Effect of initial concentration on percentage removal of Cr^{6+} by SSAC ($C_0 = 30$ mg/L, 20 mg/L, 10 mg/L, and 5 mg/L; adsorbent dose 5 g, 10 g, and 15 g; agitation speed = 120 rpm; time = 180 minutes).

available binding sites and a lack of binding sites for complexation at higher metal ion concentrations. Almost all metal ions can interact with binding sites at lower concentrations, facilitating increased adsorption [43]. Limited adsorption sites are to blame for low adsorption at higher Cr(VI) ions starting concentrations [44]. At lower concentrations, the ratio of available sites to the Cr(VI) ions initial concentration was higher, and at higher concentrations, the ratio was low; therefore, the Cr(VI) removal declined at the higher concentration at a fixed adsorbent dose and solution volume [8].

3.4. *Effect of Adsorbent Dose.* The effect of Cr(VI) sorption on adsorbent dose was investigated by varying the amount of adsorbent (5 g, 10 g, and 15 g) in the solution at pH 5, and Cr(VI) ion concentration 5 to 30 mg/L. The effect of adsorbent dose on the removal of Cr(VI) by SSAC is shown in Figure 4. Adsorption of Cr(VI) was maximum at 5 g adsorbent dose, and the efficiency was slightly decreased when the adsorbent dose was increased. The decline in adsorption ability by SSAC caused the active layer to be closed, characterized by clumps on the adsorbent, which

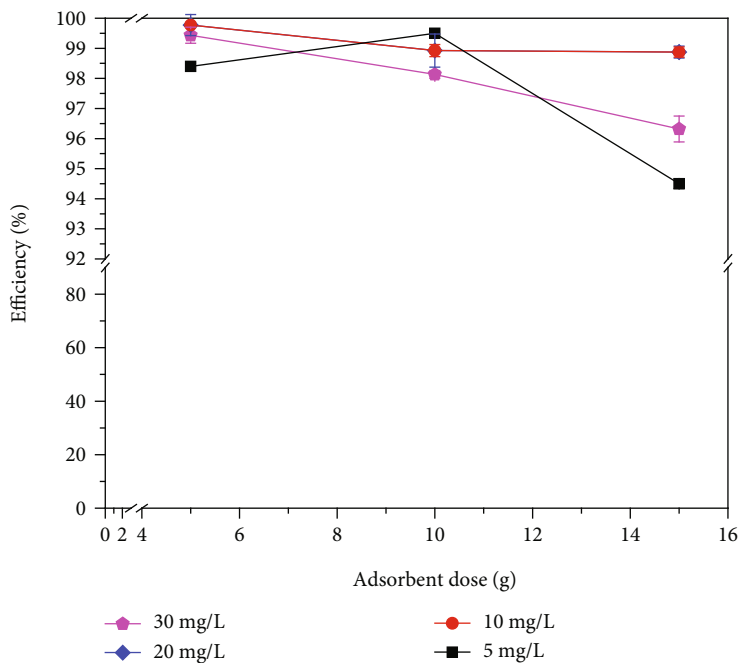


FIGURE 4: Effect of adsorbent dose on percentage removal of Cr(VI) by SSAC ($C_0 = 30$ mg/L, 20 mg/L, 10 mg/L, and 5 mg/L; adsorbent dose 5 g, 10 g, and 15 g; agitation speed = 120 rpm; time = 180 minutes).

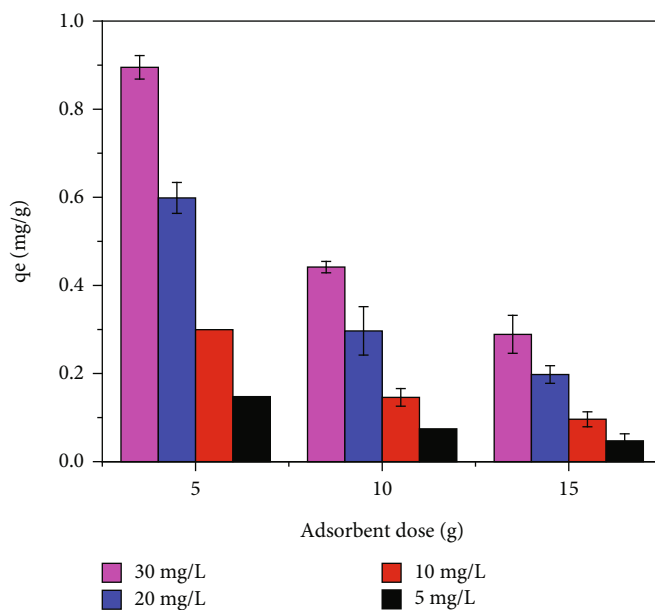


FIGURE 5: Adsorption capacity of SSAC.

reduced the effective adsorption area. This also results in overlap in the adsorption layer, which reduces the total surface area of the adsorbent [45]. The higher the mass of the adsorbent capacity of adsorption will decrease. This decrease in adsorption capacity is due to the presence of the active surface of the adsorbent, some still have not bound to the adsorbate. This study is equal to the previous studies that the limited adsorption at higher doses might be attributed to adsorbent particle aggregation and a lack of active sites for Cr(VI) adsorption [8, 46]. At constant concentration

and solution volume, increasing the adsorbent dosage causes saturation of active sites and aggregation, which reduces the adsorption capacity [8, 47].

3.5. Adsorption Capacity. The adsorption capacity determination was carried out to determine the amount of Cr(VI) metal that could be absorbed by the adsorbent SSAC in each gram.

Based on Figure 5, the adsorption capacity of Cr(VI) with SSAC adsorbent obtained the highest adsorption

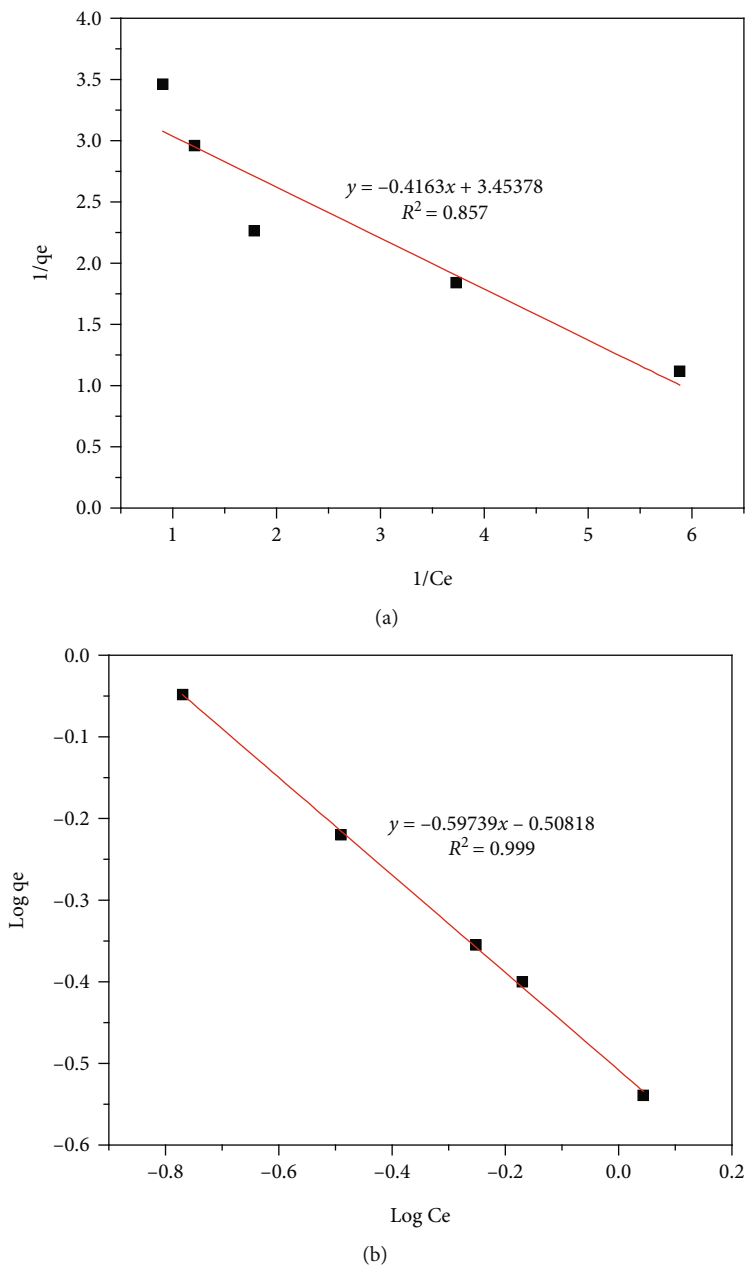


FIGURE 6: (a) Langmuir isotherm. (b) Freundlich isotherm by SSAC.

capacity at a mass of 5 g with an initial concentration of 30 mg/L. It was viewed from the analysis results that the higher the mass of the adsorbent then, the lower the adsorption capacity. This indicates that the active site of the adsorbent has not yet fully bound with the adsorbate, so the increase in adsorption capacity is inversely proportional to the mass of the adsorbent used. The adsorption capacity of the adsorbent can be increased by activation. SSAC can adsorb Cr(VI) because it contains cellulose. Cellulose is a natural polymer that can adsorb metals. Cellulose including organic compounds that are in the cell walls along with lignin plays a role to establish the structure of the plant. The presence of OH groups in cellulose causes the adsorbent to be polar because it absorbs more strongly than less polar adsorbents. The adsorption mechanism between the OH

group bound to the surface of the metal ion that is positively charged is called the ion exchange mechanism [48].

In this study, *S. saman* has outstanding performance in Cr(VI) adsorption, with the highest result adsorption capacity of 0.8949 mg/g (Figure 5). *S. saman* is natural, and agricultural products are readily available; the principal goal of their use as adsorbents is fundamentally to utilize them in a useful, straightforward, and efficient practice and to leave them to cause waste disposal problems if not being handled properly in the environment. Thus, according to the novelty result, SSAC has a low cost and is highly proposed to be practical for wastewater and large-scale applications.

3.6. Adsorption Isotherms. The isotherm adsorption is essential to describe how activated carbon performance in the

TABLE 2: Adsorption isotherm model parameters.

Monolayer adsorption isotherm model							
Langmuir			Freundlich				
q_m	K_L	R^2	χ^2	K_f	N	R^2	χ^2
0,2893	-8.4020	0.857	0.005	0.3086	-1.6595	0.999	0.000009

Note: q_m : maximum adsorption capacity (mg/g); K_L : Langmuir constant associated with adsorption capacity (L/mg); K_f : adsorption capacity (mg/g); n : intensity adsorption; R^2 : linear coefficient of determination; χ^2 : nonlinear statistical test (chi square).

adsorption process, and dissolved substances can be known in some mass of adsorbent. The purpose of the adsorption isotherm is to explain how the adsorbent interacts with the adsorbate and can describe the magnitude of the adsorption capacity. The adsorption isotherm study was modelled on the Langmuir and Freundlich isotherm. The isotherm adsorption determination was carried out in batch at an initial concentration of 30 mg/L with a mass variation (5, 10, and 15 grams) with the optimum pH at 5.

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{K_L q_m C_e}. \quad (2)$$

The Langmuir isotherm constant consists of q_m and K_L , where q_m describes the maximum capacity of the adsorbent to absorb adsorbate, and K_L is the Langmuir constant related to the affinity of the adsorption site. Langmuir isotherm assumes that on the surface of the adsorbent, several active surfaces can accommodate the adsorbate is homogeneous and occur in a single layer (monolayer). The Langmuir isotherm can explain that the adsorption can be linear, irreversible, unfavourable, or favourable with the separation factor (R_L) [49].

$$R_L = \frac{1}{1 + K_L C_o}. \quad (3)$$

If $R_L = 1$; then, adsorption that occurred is linear. If $R_L = 0$; then, the adsorption that occurs is irreversible. If $R_L > 1$; then, adsorption occurs unfavourable. Whereas if $0 < R_L < 1$; then, adsorption occurs favourable [49]. Further, to type numbers iod may not be indicated because of the value of RL negative value [50].

In the equation (Figure 6(a)), the Langmuir isotherm with adsorbent SSAC obtained a value of $q_m = 0.2893$ and $K_L = -8.4020$. The maximum adsorption capacity of Cr6+ was 0.2893 mg in one gram of the adsorbent SSAC, while the value of KL obtained had a negative intercept, resulting in a negative R_L value (-0.0040). The R_L value negative cannot be applied because it cannot describe adsorption characteristics. Therefore, the Langmuir isotherm cannot be used in the adsorption process on the adsorbent SSAC.

The Freundlich isotherm also assumes that the adsorbate is heterogeneous. The Freundlich isotherm constants K_f and $1/n$ can be obtained from the $\log q_e$ versus $\log C_e$ plot. For the adsorption of solutes from the solution, the Freundlich isotherm is described by equations.

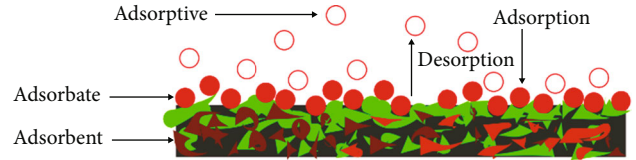


FIGURE 7: Adsorption mechanism.

$$\log q_e = \log K_f + \frac{1}{n} \log C_e, \quad (4)$$

The Freundlich isotherm constant consists of K_f and n , where K_f describes adsorption capacity, and n is the Freundlich constant associated with heterogeneity or adsorption intensity. The Freundlich isotherm model defines a heterogeneous surface. In addition, this model also does not require the heat to be uniformly distributed on the surface. The Freundlich isotherm model can also determine if adsorption is favourable, unfavourable, or irreversible using $1/n$. While $1/n = 1$, the adsorption is irreversible [49]. If the value of $1/n < 1$, then the adsorption process said is going well physically [51].

The equation (Figure 6(b)) obtained the value of adsorption capacity (K_f) = 0,3086 mg/g, where the capacity of adsorption metal Cr⁶⁺ is adsorbed by 0.3086 mg in one gram of the adsorbent SSAC. The value of n is -1.6595, where the value of $1/n = -0.6026$ ($1/n < 1$) shows that the adsorption process is going well physically.

According to Table 2, the value of R^2 , the maximum obtained from the isotherm adsorption model on the adsorbent SSAC, is isotherm Freundlich with R^2 of 0.999. This is supported by the value of χ^2 a minimum of 0.000009. It can be concluded that the adsorption of Cr(VI) by SSAC occurs in a monolayer (single layer), and the surface is heterogeneous. The monolayer is shown in Figure 7 where the adsorbate adsorbed forms a single layer on the surface of the adsorbent. The heterogeneous surface on the adsorbent has various forms, and each of these surfaces has adsorption power. Following the statement [35], biomass is a heterogeneous material. The adsorption process is heterogeneous and has two stages, namely, the transfer of the adsorbate from the solution phase to the adsorbent surface and the adsorption process on the adsorbent surface [52].

4. Conclusion

According to the experiment, the adsorption efficiency of hexavalent chromium by utilizing the SSAC is maximum at 99.90% with a mass of the adsorbent of 5 g with an initial

concentration of 20 mg/L. The highest adsorption capacity of 0.8949 mg/g with an initial concentration of 30 mg/L and an adsorbent mass of 5 g. The adsorption data for hexavalent chromium are utilizing SSAC best fit to Langmuir isotherm model ($R^2 = 0.999$). The material characterization demonstrated that the carbon activated with K_2CO_3 and the pyrolysis process has an impact on the surface area of activated carbon. Due to the excellent performance of the SSAC on the removal of hexavalent chromium, this potential material-activated carbon from *Samanea saman* could be applied in the industrial process for sequestration of heavy metals in the wastewater.

Data Availability

The research data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no potential conflicts of interest regarding the publication of this paper.

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