Characterization and Adsorption Performance of Teak Sawn Derived Activated Carbon for Cr(VI) Removal from Batik Industry Effluents

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Abstract. Sawn timber waste requires proper disposal management owing to its potential to pollute water. Teak (*Tectona grandis* L.) sawn timber residue can be converted to activated carbon for heavy metal adsorption. This study aimed to characterize *T. grandis* activated carbon, determine its maximum adsorption capacity for Cr(VI) in batik wastewater, and evaluate the adsorption isotherm models. The sawn teak was carbonized, chemically activated with 1 M HCl for 24 h. Characterization was performed using SEM and FTIR. Adsorption experiments were conducted with 0.5 L of wastewater from the batik hand-drawn industry in Giriloyo. Cr(VI) was adsorbed using 0.5–3.0 g of activated carbon and with the contact time of 30–240 min. SEM revealed pores filled with adsorbate, whereas FTIR showed new bands at 600–500 cm^{-1} corresponding to the Cr–O spectral bond. The adsorption followed the Freundlich isotherm model, with a maximum capacity of 0.027 mg/g using 0.5 g at contact time of 30 min. The highest removal efficiency of (91%) was achieved with 3.0 g at 120 minutes contact time. These findings demonstrate that *T. grandis* activated carbon is an effective adsorbent for Cr(VI) removal, offering potential applications in sustainable batik wastewater treatment.

1 Introduction

Yogyakarta is a province in Indonesia that produces hand-drawn batik textile. The hand-drawn batik process produces liquid waste that can damage or pollute the environment, especially water bodies. The textile industry, from the beginning of the process, uses chemicals containing heavy metals, including dyeing, rolling, and washing. Many batik industries prefer synthetic dyes over natural dyes because of their greater availability, wider color variety, affordable price, and practicality. However, synthetic dyes pose a greater risk of environmental damage than do natural dyes [3].

The characteristics of batik industrial wastewater vary widely, depending on the chemicals and type of fabric used. In addition to the high Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), batik wastewater can contain both organic and inorganic compounds. Organic compounds include fats, waxes, and surfactants, while inorganic compounds include Cr, Co, Ni, As, Cu, Pb, Cd, and Hg [1, 3, 10]. The heavy metal content of batik wastewater is due to the use of synthetic dye enhancers such as indigosol in batik fabrics.

Teak wood (*Tectona grandis* L.) is a wood with high economic value and is widely used in various products, including indoor and outdoor furniture, building materials, and handicrafts. The waste or remaining teak sawn timber can be used as fuel or as the main raw material for producing activated carbon. Teak sawn timber in the form of activated carbon has the potential to act as an adsorbent for heavy metals, including Cr, Cd, Cu, and Pb, in aqueous media [2, 4, 6, 7, 9]. Nguyen et al. (2019) also reported that the modification of teak wood carbon using a hydrothermal process can be used to absorb Cu(II) and Cd(II) [5]. It is also beneficial for removing ammonia from shrimp ponds, which may potentially decease shrimp [12].

Adsorption is a common method for wastewater treatment because it is both economical and practical. Various alternative adsorbents from natural materials have been widely used to reduce the concentration of heavy metals and dyes in wastewater. One material that can be easily used as an adsorbent is activated carbon, a porous solid with a carbon content of 85-95%. The adsorption capacity of activated carbon is determined by the surface area of the particles. This adsorption capacity can be increased by activation using chemicals such as HCl, HNO_3, and others or by heating at temperatures of 500-900 °C. The physical and chemical properties of activated carbon may change. Metal adsorption in teak wood carbon is possible because of

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the presence of active groups in teak wood carbon. The composition of teak wood includes 25% lignin, 32% cellulose, 8% hemicellulose, and 6.4% ash [8]. According to Wijaya et al. these compounds are important in producing activated carbon [11].

This study aimed to investigate the adsorption isotherm of Cr(VI) contained in the wastewater of batik industry in Giriloyo Village, Imogiri District, at Bantul Regency, using activated carbon from teak sawn wood. We investigated the effect of activated carbon mass and stirring time on adsorption equilibrium. Changes in the active groups and surface morphology of teak wood carbon before and after contact with Cr(VI) were be studied using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM) characterization.

2 Materials and Methods

2.1 Materials

Distilled water, HNO_3 65% (Merck), HCl 37% (Merck), teak sawn, and batik wastewater were used. Teak sawn was collected from the Maju Furniture Store on Jl. Cantel 14 Yogyakarta. Batik wastewater was obtained from the batik hand-drawing industry in Giriloyo. The tools used included a digital scale, a pH meter, stirring (Velp jar test JLT 4), an oven (WTC binder 7200), glassware (Iwaki), and Whatman No. 42 filter paper. The metal content in the solution was analyzed using UV-vis spectrophotometry (Genesys 10s UV-vis). To determine the surface morphology of the activated carbon using SEM (Phenom Desktop ProXL), the determined changes in the functional groups were determined using FTIR (Nicolet Avatar 360 IR).

2.2 Preparation and Characterization Materials

Activated carbon was made by preparing 5-10 cm teak sawn wood. Teak sawn wood was collected and dried in the sun for three days to remove the water content, then carbonized using an electric retort at a temperature of 450 °C for approximately 2 h. Carbon was air-dried, ground, and sieved through a mesh size of 100. The activation of teak wood carbon was performed using a chemical method. A total of 600 g of teak ground carbon was soaked in a 1M HCl solution for 48 h, filtered using filter paper and washed with distilled water until pH 7. Teak activated carbon was obtained after being dried in an oven at ± 110 °C for 3 h.

2.3 Cr(VI) Adsorption

2.3.1 Effect of Adsorbent Mass

The absorption percentage is defined as the difference in the Cr(VI) ion concentration in batik wastewater after soaking with teak activated carbon adsorbent, compared to the initial concentration. Mathematically, this equation is formulated as follows:

$$Removal\ (\%) = \frac{C_o - C_e}{C_o} \times 100\% \qquad (1)$$

C_o : initial concentration (mg/L)
C_e : final concentration (mg/L)

Another parameter to be measured was the amount of Cr(VI) adsorbed on the mass of teak wood carbon used. This parameter was used to determine the efficiency of Cr(VI) adsorption on the teak wood activated carbon adsorbent.

$$qe = \frac{v(C_o - C_e)}{m} \qquad (2)$$

qe : adsorption capacity/mass of adsorbate adsorbed per unit mass of adsorbent (mg/g)
C_o : initial concentration (mg/L)
C_e : final concentration (mg/L)
m : adsorbent mass (g)
ν : adsorbate volume (L)

2.3.2 Adsorption Isotherms

The adsorption isotherm model is a balanced equation for the adsorption process that was used to study the adsorption mechanism. The Langmuir and Freundlich isotherm models were constructed using linear equations. The selection of an isotherm model for adsorption was based on the R^2 value between 1/qe and $1/C_e$ (Langmuir isotherm) and log C_e and log qe (Freundlich isotherm), with the R^2 value closest to 1 being selected.

Langmuir equation:

$$C_e/qe = 1/(b.qm) + C_e/qm \qquad (3)$$

$$1/qe = 1/(b.qm)\ 1/C_e + 1/qm \qquad (4)$$

C_e : adsorbate concentration in the solution phase (mg/L)
qe : adsorption capacity/mass of adsorbate adsorbed per unit mass of adsorbent (mg/g)
qm : adsorption capacity constant (mg/g)
b : adsorption equilibrium constant (L/mg)

Freundlich equation:

$$\log qe = \log Kf + 1/n \log C_e \qquad (5)$$

qe : adsorption capacity/mass of adsorbate adsorbed per unit mass of adsorbent (mg/g)
Kf : Freundlich adsorption capacity constant (mg/g)
1/n : Freundlich intensity factor
C_e : concentration of adsorbate in the solution phase (mg/L)

3 Result and Discussion

3.1 Batik Waste Quality

Batik wastewater samples were taken from the batik industry located in Giriloyo, Imogiri, Bantul, at Special Region of Yogyakarta.

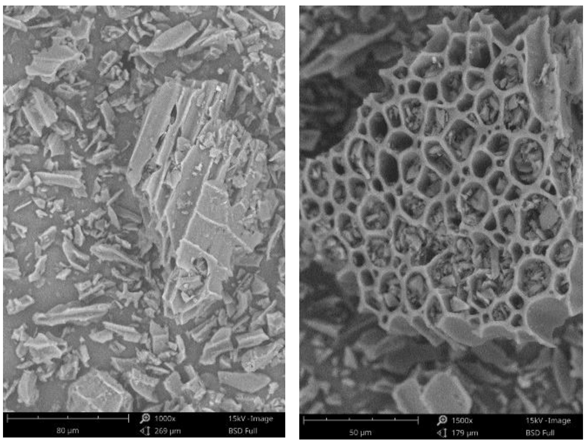
Table 1. Characteristics of Giriloyo Batik Wastewater.

Parameter	Unit	Result	*Quality standard	Test method
TSS	mg/L	4126	60	SNI 06-6989.3-2004
TDS	mg/L	2780	2000	SNI 06-6989.27-2005
pH	-	6.5	6-9	digital pH
Cr(VI)	mg/L	0.0597	0.05	Spec. UV-vis
Pb	mg/L	0.0099	1	SNI 09-6989.46-2005
COD	mg/L	18228.16	85	SNI 6989.72-2009
BOD	mg/L	1005.49	250	SNI 06-6989.2-2004

*Source: Special Regional Regulation of Yogyakarta regarding Wastewater Standard number 7, 2016.

Table 1 shows that the characteristic of Cr(VI), TSS, TDS, COD, and BOD content of Giriloyo Batik wastewater exceeded the quality standards. However, further research will only be conducted on Cr(VI) metal content.

3.2 SEM Analysis of Teak Wood Activated Carbon



a b

Fig 1. SEM analysis of the surface of teak wood carbon adsorbent: **a**) before adsorption (1000x magnification), **b**) after Cr(VI) adsorption (1500x magnification).

Fig 1a shows the morphology of activated carbon. The activation process causes pore formation on the surface of activated carbon. Pores can be observed in the image. Fig 1b shows the morphology of activated carbon after Cr(VI) adsorption. The pores were filled with particles or substances absorbed from batik wastewater.

3.3 FTIR Analysis of Teak Wood Activated Carbon.

Fig 2 shows the identification of the functional groups in the activated carbo adsorbent. The FTIR spectrum of activated carbon before adsorption shows an absorption band at 3290–3400 cm^{-1} associated with the O–H functional group, a band around 1689 cm^{-1} associated with the C=O functional group, a band of 1581 cm^{-1} for aromatic C=C functional group, and a band of 1160–1165 cm^{-1} for C–O functional group. The FTIR results of activated carbon after Cr(VI) adsorption shows a weakened O–H functional group, shift of C=O functional group from 1689 cm^{-1} to 1680 cm^{-1}, and the C–O functional group from 1165 cm^{-1} to 1160 cm^{-1}. In addition, a new band appears in the fingerprint region of 600-500 cm^{-1} which was suspected due to the association of Cr–O bound.

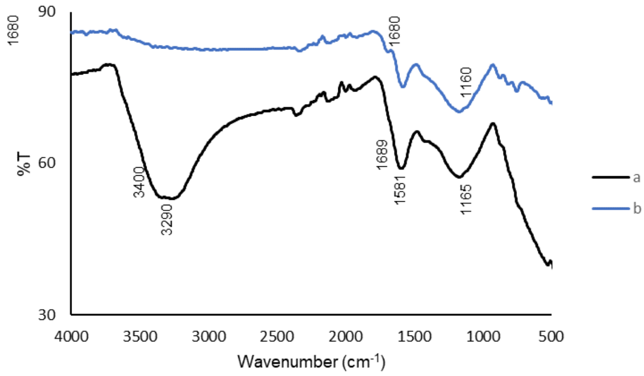


Fig 2. FTIR spectra of teak wood carbon: a) before contact with wastewater, b) after contact with wastewater Cr(VI).

3.4 Cr(VI) Adsorption

The adsorption of Cr(VI) metal began by determining the optimum contact time and weight of the teak wood activated carbon. Contact time is one of the factors that affect the optimum adsorption capacity over a certain period of time. The adsorbent mass was used to determine the minimum amount of adsorbent that could be used for adsorption. The determination of the optimum adsorption time was carried out with stirring variations of 30, 120 and 240 min, whereas the determination of the optimum weight of the mesh 100 teak wood activated carbon adsorbent was carried out with mass variations of 0.5, 1, 2, and 3 g. The volume of batik waste used was 500 mL. The initial concentration of Cr(VI) adsorbed on the batik wastewater was 0.0597 mg/L, with a stirring speed of 60 rpm.

Table 2a. Adsorption results with a stirring time of 30 min.

Weight adsorbent (gr)	C_e [Cr(VI)] stirring 30 min (mg/L)			Average C_e [Cr(VI)]
	I	II	III	
0.5	0.035	0.028	0.035	0.033
1	0.022	0.016	0.022	0.019
2	0.016	0.016	0.016	0.016
3	0.009	0.003	0.009	0.007

Table 2b. Adsorption results with a stirring time of 120 min.

Weight adsorbent (gr)	C_e [Cr(VI)] stirring 120 min (mg/L)			Average C_e [Cr(VI)]
	I	II	III	
0.5	0.029	0.048	0.054	0.044

Weight adsorbent (gr)	C_e [Cr(VI)] stirring 120 min (mg/L)			Average C_e [Cr(VI)]
	I	II	III	
1	0.033	0.024	0.038	0.031
2	0.018	0.015	0.015	0.016
3	0.003	0.009	0.003	0.005

Table 2c. Adsorption results with a stirring time of 240 min.

Weight adsorbent (gr)	C_e [Cr(VI)] stirring 240 min (mg/L)			Average C_e [Cr(VI)]
	I	II	III	
0.5	0.033	0.034	0.033	0.033
1	0.026	0.026	0.017	0.023
2	0.017	0.019	0.017	0.018
3	0.009	0.011	0.011	0.010

C_e is the concentration of the adsorbate in the solution. A higher C_e indicates less effective adsorption by the adsorbent. Tables 2a, 2b, and 2c show that the most effective removal capacity of the adsorbent was achieved when 3 g of activated carbon was stirred for 120 min (Table 2b), with an effective removal of approximately 91% (Fig 2a). Fig 3 illustrate the adsorption of Cr(VI) using teak wood activated carbon.

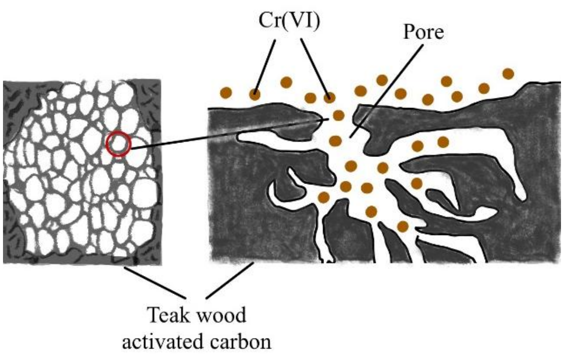


Fig 3. Adsorption illustration of Cr(VI) using Teak wood activated carbon.

3.5 Adsorption Effectiveness and Adsorption Capacity of Cr(VI)

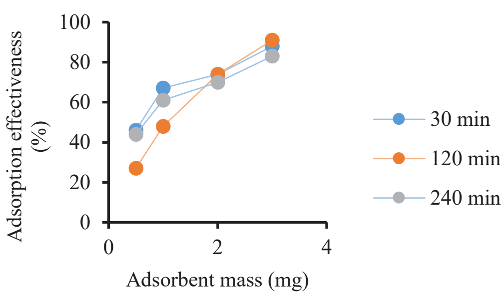


Fig 4. Weight of teak wood activated carbon adsorbent vs adsorption effectiveness Cr(VI).

Fig 4 shows that at stirring times of 30, 120, and 240 min, the heavier adsorbent resulted in at the more effective adsorption process. Increasing the adsorbent weight increases the adsorption effectiveness because it increases the number of particles and the active surface area, so that more adsorbate can be bound.

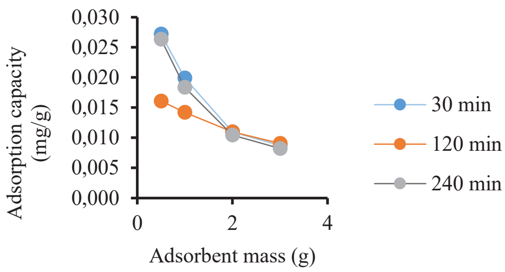


Fig 5. Weight of teak wood activated carbon adsorbent with adsorption capacity Cr(VI).

Fig 5 shows that at stirring times of 30, 120, and 240 min, the heavier adsorbent lowers the adsorption capacity. Increasing the adsorbent weight can cause all active sites to be unexposed or not all of them can interact with the adsorbate, so that some parts of the adsorbent become inefficient. The decrease in the adsorption capacity is caused by the presence of active sites on the adsorbent that are not bonded with the adsorbate.

Fig 6 shows the dynamic relationship between stirring time and adsorption effectiveness. A shorter stirring time would increase the effectiveness because the contact between the adsorbent and adsorbate is optimal. However, at longer stirring time can reduce the effectiveness of the heavier absorbent because the adsorbate can be released back from the pores, but not to the lighter absorbate.

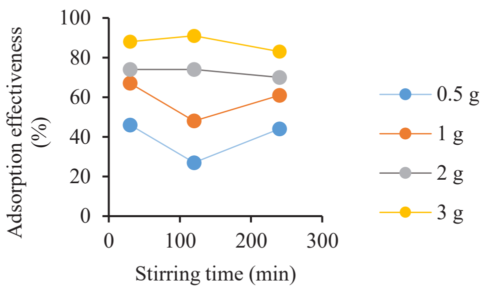


Fig 6. Stirring time vs adsorption effectiveness Cr(VI).

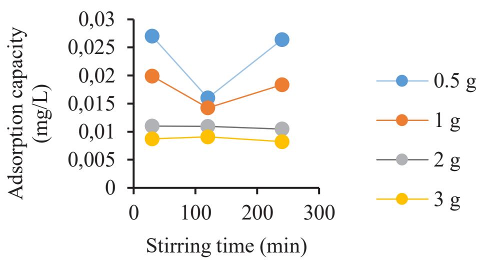


Fig 7. Stirring time vs adsorption capacity Cr(VI).

Fig 7 shows the relationship between the stirring (contact) time and adsorption capacity which is a decrease in adsorption capacity until a certain stirring time and a re-increase in the adsorption capacity when the stirring time is extended. A sufficient stirring time provides an opportunity for interaction between the adsorbent and adsorbate. However, it was predicted that an extensive stirring time would desorb the from absorbate to the wastewater.

3.6 Isotherm adsorption

Table 3 shows that at stirring times of 30, 120, and 240 min, the R^2 value of the Freundlich equation is greater than the R^2 value of the Langmuir equation. Fig 8 shows a linear plot for determination of adsorption constant with Freundlich and Langmuir equilibrium model. This indicated that the adsorption of Cr(VI) in batik processing wastewater using teak wood activated carbon followed the Freundlich equation. The Freundlich equation indicates that multilayer adsorption occurs on heterogeneous adsorbent surfaces which may be physisorption. The adsorbate in the physisorption process is not bound tightly, therefore, it can move on the adsorbent surface, and the remaining surface can be filled with other adsorbates. At stirring time of 30 and 120 min, n index values > 1indicate that the adsorption runs well, whereas at a stirring time of 240 min, n index values < 1 indicate a poor adsorption process. The Freundlich isotherm model for physical adsorption processes is driven by van der Waals forces, or weak attractive forces between the adsorbate and the adsorbent molecules.

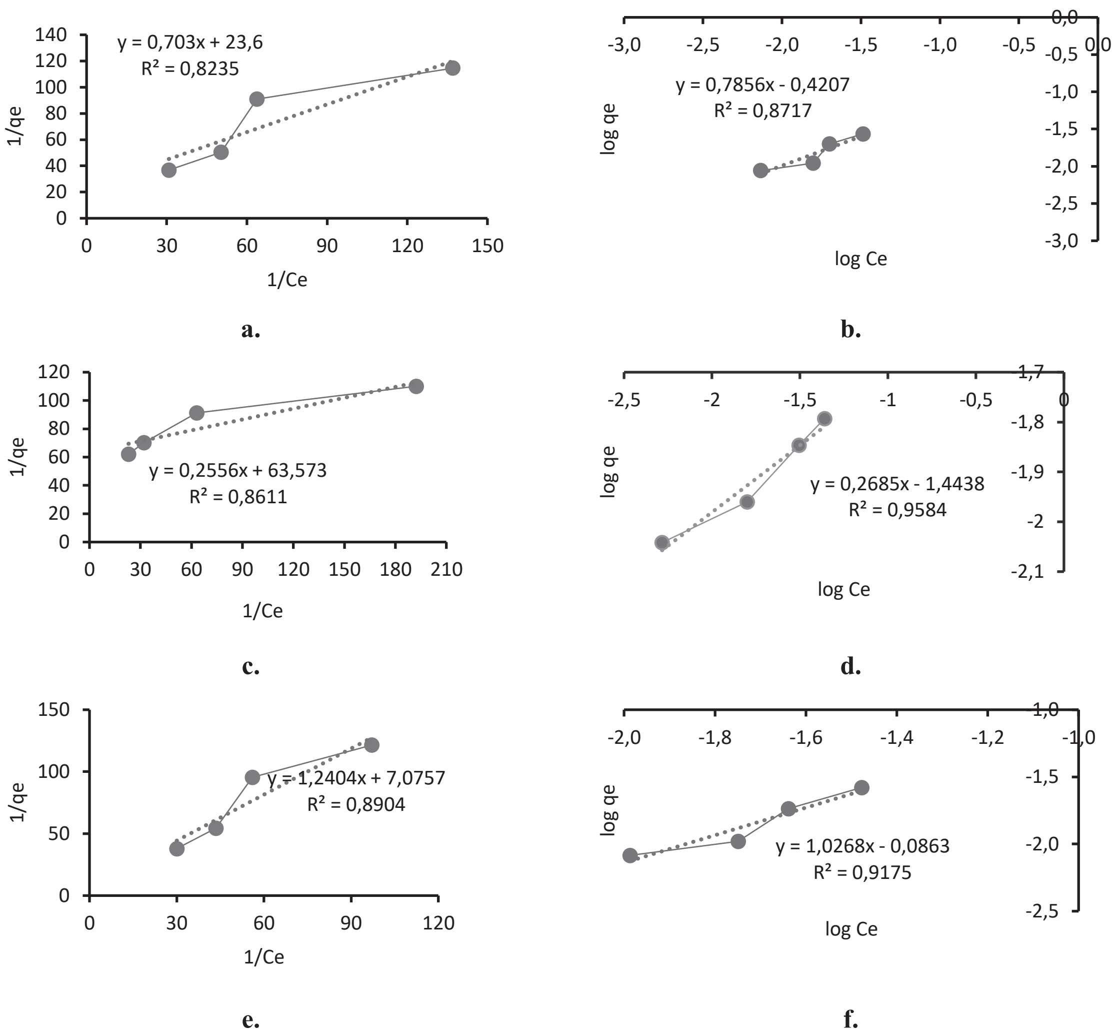


Fig 8. Linear plot for determination of adsorption constant with Freundlich and Langmuir equilibrium model: a) Langmuir isotherm stirring time 30 minutes, b) Freundlich isotherm stirring time 30 minutes, c) Langmuir isotherm stirring time 120 minutes, d) Freundlich isotherm stirring time 120 minutes, e) Langmuir isotherm stirring time 240 minutes, f) Freundlich isotherm stirring time 240 minutes

Table 3. Isotherm Langmuir and Freundlich.

Time (min)	Langmuir				Freundlich				
	Linear equation	1/qm	1/b.qm	R²	Linear equation	Kf	n	1/n	R²
30	y = 0.7030x + 23.600	0.042	33.570	0.8235	y = 0.7856x - 0.4207	0.379	1.265	0.790	0.8717
120	y = 0.2556x + 63.573	0.016	248.721	0.8611	y = 0.2685x - 1.4438	0.035	3.724	0.269	0.9584
240	y = 1.2404x + 7.076	0.141	5.706	0.8904	y = 1.0268x - 0.0863	0.819	0.973	1.027	0.9175

4 Conclusion

SEM revealed the activated carbon pores filled with adsorbate, while FTIR showed new bands at 600–500 cm^{-1} corresponding to Cr–O bound. The adsorbent from teak wood activated carbon was able to reduce the heavy metal content of Cr(VI) in batik wastewater by 91.2%. The optimum adsorption capacity of Cr(VI) was 0.027 mg/g at the stirring time of 120 min with an adsorbent mass of 3 g. The adsorption of batik liquid waste with activated carbon from teak wood followed the Freundlich adsorption model with an R^2 maximum value of 0.96.

Further study is required to analyze the financial status of this product, wether it is feasible or not. It was predicted that this might be feasible because the raw material was waste and could be collected for free, which would reduce the costs.

Author Contribution

DE: conceptualization, investigation, data Processing, and manuscript writing; WNP: investigation, data collection, and original draft writing; ADNL: data analysis, manuscript writing, and editing; RA: data analysis, manuscript writing, and editing

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