The activated carbon produced from mayan bamboo 
(*Gigantochloa robusta Kurz*) and its application as dye removal

L Efiyanti*, D A Indrawan, N Hastuti, and S Darmawan

Forest Product Research and Development Center, Ministry of Environment and Forestry, Bogor, 16118, Indonesia

*Email: lisnaefiyanti@gmail.com

**Abstract.** Bamboo pyrolysis was carried out at a temperature of 400°C for 4 hours to obtain a carbon as a pyrolysis product. The carbon soaked using potassium hydroxide (KOH) 5.35 M for 24 hours. The carbon obtained heated in a reactor at a temperature of 800°C for 5 hours then washed and neutralized until activated carbon obtained. The characterization of activated carbon conducted based on the Indonesian National Standard (SNI 06-3730-1995). The methylene blue adsorption process using a concentration of 50, 100, 150, and 200 ppm for 120 minutes reaction with the contact time variation are 30, 60, 90, 120,150, and 180 minutes in optimum concentration. The result shows that activated carbon has good quality based on SNI 06-3730-1995. The optimum methylene blue removal by bamboo activated carbon reached 99.77% in 120 minutes reaction and the adsorption type follows Langmuir isotherm.

1. **Introduction**

Bamboo as lignocellulose biomass has wide benefits, including as a raw material for activated carbon. The application of bamboo activated carbon in this research as a dye removal in the methylene blue adsorption process. The methylene blue is a cationic dye that is water soluble with stable color [1, 2]. Methylene blue commonly used in textile, cosmetics, and paper industries. The content of methylene blue in the water based on KepMen LH No. 51/MENLH/10/1995 not recommended to exceed the threshold (5-10 mg/L) because it can give rise to the environmental pollution. If the excess dyes on water released into the environment such as water, soil, lakes, and oceans, it will affect serious environmental damage, not only resulting in undesirable color changes but also disrupting the health of aquatic and human organisms.

The adsorption method widely used and considered as one of the promising methods for processing dyes [3]. Several raw materials usually used as an adsorbent include zeolite [4,5], soil [6,7] clay [8], chitosan and activated carbon [9]. Graphene as an advanced material used as adsorbent [10], but the acquisition of this product complicated and requires a high cost therefore low-cost green technology and products are needed.
Activated carbon from biomass is relatively effective and low cost because it is abundant and not utilized properly. Activated carbon has a prospective industrial use due to superior characteristics, such as high surface area, good chemical stability, and has unique structural properties [11]. The raw materials for activated carbon obtained from forestry, agriculture, and waste biomass [12]. One used as raw material for activated carbon is bamboo. Bamboo is a tropical plant biomass, which is easily found in Indonesia [13] with the third largest quantity in the world [14]. Bamboo contains cellulose, hemicellulose, lignin, and silica [15] which can be converted into other products such as activated carbon or natural silica. Mayan bamboo (Gigantochloa robusta Kurz) has the potential as a raw material for activated carbon because it has a low water content with high lignin content as well as with high iodine number.

The activated carbon from mayan bamboo as an adsorbent of HCl and NaOH resulting in adsorption capacity of 1.3 mmol/g and 6.1 mmol/g respectively, higher than the commercial activated carbon [16]. Activated carbon from andong and ater bamboo used as diazinon insecticide adsorbent with an adsorption capacity of 4.63 mg/g and 1.763 mg/g [17]. The production and application of activated carbon from mayan bamboo as methylene blue removal necessary to study to know the potential of bamboo activated carbon as an adsorbent for dye removal. Hopefully, it will be a low cost and green adsorbent in the future.

2. Materials and Methods

2.1 Materials

The raw material used in this study is mayan bamboo (Gigantochloa robusta Kurz). The chemicals used are KOH pellets, 10% HCl, methylene blue, distilled water, and Whatman filter paper. The equipment used in this research is glass equipment (Pyrex, Iwaki), furnace, vacuum desiccator, oven, grinding machine, pyrolysis reactor with a capacity of 2 kg, electrical retort capacity of 0.5 kg, 100 mesh sieve, analytical balance (Libror EB330 Shimadzu), digital pH meter, 100 ml crucibles. The analysis instrument used was a UV-Vis spectrophotometer (Shimadzu-1700, Japan).

2.2 Methods

2.2.1 Activated carbon production

The bamboo is cut into a size of about 5 x 2.5 cm and pyrolyzed at a temperature of 400°C for 4 hours. The carbon obtained is then cooled and grounded. The carbon immersed in a 5.35 M KOH solution for 24 hours, drained and put into an electric retort to be heated at 800°C for 5 hours. Furthermore, the activated carbon neutralized using distilled water and dried so that the activated carbon is ready to use.

2.2.2 Characterization and activated carbon application as methylene blue adsorption

The quality of bamboo activated carbon analyzed based on SNI 06-3730-1995 method including moisture content, ash content, volatile matter content, and fixed carbon. The process of methylene blue adsorption by activated carbon bamboo follows the research procedure of [18]. A standard solution of methylene blue dyes prepared by dissolving 0.1 g of methylene blue into 100 ml of distilled water to obtain a solution with a concentration of 1000 ppm. Then several variations concentration of methylene blue were made into 50 ppm, 100 ppm, 150 ppm, 150 ppm, and 200 ppm adsorbed by 0.1 g of activated carbon for 2 hours. After the adsorption process, the solution filtered and analyzed using a UV-Vis spectrophotometer at a wavelength of 665 nm. Furthermore, under optimum adsorption conditions, 25 ml of solution was taken and 0.1 g of activated carbon added with variations for 30, 60, 90, 120, 150, and 180 minutes. The resulting solution then analyzed following the same procedure.

The equation of adsorption process:

\[ \frac{X}{m} = \frac{V (Co-Ca)}{m} \] (1)
\[ Q = \frac{C_o - C_e}{C_o} \times 100\% \]  \hspace{1cm} (2)

\[ \frac{C_e}{x_e/m} = \frac{1}{ab} + \frac{1}{a} C_e \]  \hspace{1cm} (3)

where:
- \( X/m \) = adsorption capacity (mg/g)
- \( V \) = solution volume (L)
- \( C_o \) = initial concentration of methylene blue (mg/L)
- \( C_a \) = final concentration of methylene blue (mg/L)
- \( m \) = adsorbent weight (g)
- \( Q \) = methylene blue removal (%)  
- \( a \) = adsorption maximum capacity (mg/g)
- \( b \) = equilibrium constant (l/mg)

3. Results and Discussion

3.1 Characterization of activated carbon from mayan bamboo

In general, the process of carbon production is through the pyrolysis method with limited oxygen and the activation process using chemical or physical activators. In this study, pyrolysis carried out at 400°C followed by chemical activation using KOH and reheated at 800°C so the activated carbon obtained.

![Figure 1. Activated carbon characterization based on SNI 06-3730-1995](image)

The characterization of activated carbon fulfilled the requirements of SNI 06-3730-1995 (presented in figure 1). Indonesian National Standard of activated carbon requires the moisture content \( \leq 15\% \), ash content \( \leq 10\% \), volatile matter content \( \leq 25\% \), and fixed carbon \( \geq 65\% \). The water content, ash content, and volatile matter expected to be low so that the activated carbon is more able to adsorb the adsorbate. So, as it can block/close the surface and pore of the carbon. For the fixed carbon, this content indicates the purity of activated carbon, the higher fixed carbon expected that the quality will be better, and have more active sites for the adsorption process. The quality of activated carbon influenced by the carbon activation process. The activation process can remove impurities on the carbon, open pores, and enlarge the surface area so the activated carbon has better quality than without the activation process.
3.2 Application of activated carbon on methylene blue adsorption

The methylene blue adsorption process by bamboo activated carbon conducted to determine the potential of activated carbon as an adsorbent. Based on the calculation results, the final concentration of methylene blue, adsorption capacity, and the removal percentage of methylene blue can be determined as shown in Table 1.

Table 1. Methylene blue adsorption data at various initial concentrations

| Co (ppm) | Ce (ppm) | Ce/(Xe/m) | Q (%) | X/m (mg/g) | log Ce |
|---------|----------|-----------|-------|------------|-------|
| 50      | 0.191    | 0.0139    | 99.65 | 13.7022    | -0.7189|
| 100     | 0.230    | 0.0092    | 99.77 | 24.9425    | -0.6383|
| 150     | 1.134    | 0.0305    | 99.24 | 37.2165    | 0.0546 |
| 200     | 1.690    | 0.0341    | 99.15 | 49.5775    | 0.2278 |

Figure 2. Effect of the initial concentration of methylene blue on the percentage of methylene blue removal

The percentage of methylene blue removal decreased after optimum state when the initial concentration of methylene blue increased (Figure 2). The highest percentage removal of methylene blue reached 99.77% at 100 ppm of initial concentration. The increasing of initial methylene blue until the optimum state will increase the adsorption capacity due to the activated carbon surface was occupied with methylene blue molecules [19,20]. The saturation occurs when the initial concentration of methylene blue increased above 100 ppm because, in this condition, the number of active sites is not enough to adsorb methylene blue with a higher concentration [21]. The higher dose of adsorbent required for higher adsorbate concentrations. The increasing initial concentration will decrease the methylene blue removal [22].

Based on the equation, we can determine the type of methylene blue adsorption. Through the plot of Ce/(Xe/m) and the final concentration of methylene blue, the Langmuir isotherm graph with an R² value of 0.932 while Freundlich isotherm with an R² value of 0.8521 calculated from Ce/(Xe/m) and Ce logarithm. These results can be shown that the Langmuir isotherm is more suitable for adsorption of methylene blue because of R² values close to 1. The adsorption isotherm used to analyze the interactions between the adsorbent and adsorbate. The Langmuir and Freundlich isotherms can describe the process of methylene blue adsorption on bamboo activated carbon. Langmuir isotherm shows the adsorption process of monolayer interaction, activated carbon has homogeneous surface and adsorbate evenly
adsorbed on the surface [11]. Based on the calculation of the $R_L$ value ($R_L = 0.0027 - 0.0108$), it can be seen that the adsorption process is favorable, because of the value of $0 < R_L < 1$ ($R_L > 1$: unfavorable, $R_L = 0$: irreversible, $R_L = 1$: linear) [15]. $K$-value from the equation obtained 1.8295, is Langmuir's constant which states the relationship of methylene blue and adsorbent. The higher of $K$-value, the affinity of methylene blue to the adsorbent will be higher.

![Isoterm Langmuir](image1.png)

Isoterm Langmuir

![Isoterm Freundlich](image2.png)

Isoterm Freundlich

**Figure 3.** Methylene blue adsorption types by activated carbon

The research result is better than Latupeirissa *et al.* [18] who found that the adsorption capacity of methylene blue adsorption and removal percentage by activated carbon with the same condition are 23.18 mg/g and 92.72% respectively. Nuchar (commercial AC) used for methylene blue adsorption resulting in 21.5 mg/g adsorption capacity. Activated carbon from ashitaba waste and walnut peel on adsorption of methylene blue produce the adsorption capacities of 381.88 and 400.11 mg/g, respectively [24]. The conditions used were with a methylene blue solution of 200 ml, as much as 0.1 g adsorbent, agitation rate of 300rpm for 540 minutes at a concentration of 0-50 mg/L. Activated carbon/cellulose composite for methylene blue removal and the maximum adsorption capacity reached 103.66 mg/g for 24 hours adsorption process [25]. Several studies have a higher adsorption capacity compared with this research due to different conditions, such as higher initial concentration, adsorbent weight and longer contact time.

![Figure 4](image3.png)

**Figure 4.** The effect of contact time to the removal percentage of methylene blue (4a) and the final concentration of methylene blue (4b).

As shown in Figures 4a and 4b, we can see the relationship between the use of contact time in the adsorption process with the final concentration and removal percentage of methylene blue. The increase
of contact time in the adsorption process, the percentage removal of methylene blue increased to an optimum point of 99.77% with a final concentration of 0.23 ppm at 120 minutes. The longer contact time will make methylene blue adsorbed more on the adsorbent because it provides longer and intense interactions. However, when the contact time continuously increased, the percent of removal can decrease because of the surface and pore of the adsorbent filled with methylene blue [26]. This result is following Sahu et al. [23] which obtained an optimum contact time of 120 minutes with maximum removal of a percent was found 98.6%, and then the saturation occurred in the adsorption process.

Bamboo as a raw material for activated carbon by pyrolysis with the addition of nitrogen and KHCO₃ as activators for the methylene blue adsorption process with an adsorption capacity of 499.3 mg/g [27]. Adsorption of methylene blue is generally longer than phenol, and a decrease in the adsorption rate of methylene blue is due to the internal diffusion of large molecules besides filling the pores during the adsorption process. Methylene blue has a large molecule with an aromatic structure so that it has a positive interaction with the functional group and generally influenced by the adsorbent functional group so it can make π-π bonds. The mechanism of methylene blue adsorption on activated carbon explained by 3 processes including π-π stacking between aromatic of methylene blue and activated carbon, electrostatic interactions and hydrogen bonds between CO and OH groups of activated carbon with amine groups on methylene blue [10,28].

4. Conclusion
The activated carbon from mayan bamboo has fulfilled the requirements of the Indonesian National Standard. This activated carbon has a good potential as an adsorbent for dye removal (methylene blue), and the result shows that the optimum methylene blue removal by bamboo activated carbon reached 99.77% in 120 minutes reaction and the adsorption type follows Langmuir isotherm. To improve the quality and adsorption capacity of activated carbon, further research may use different activator or modify adsorption process with varying pH, temperature, and higher doses of adsorbent.

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