Facile Preparation of Scalable Bamboo-Derived Activated Carbon for Efficient Wastewater Treatment

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Water contamination has reached crisis proportions due to the rapid development of industrial operations. Humans, animals, and aquatic life are all at risk of accumulating non-biodegradable heavy metals and dyes in the water supply. The adsorption process using activated carbon was identified as the most efficient, economical, and facile method. Activated carbon has gained widespread popularity because of its specialty as an adsorbent in wastewater treatments. In addition, the abundance and inexpensiveness of local bamboo can be explored in producing a cheaper and more sustainable source of commercially activated carbon. Hence, this study aimed to investigate the optimal parameters for effective activated carbon production using *G. albociliata*, a bamboo species by characterizing its material properties and adsorption ability. Fourier infrared spectra and scanning electron microscopy were employed to identify the functional groups and surface porosity of the activated carbon produced. The adsorption abilities of the heavy metals were determined by atomic adsorption spectroscopy and via the adsorption of dyes by ultraviolet-visible analysis. This study revealed that the bamboo-based activated carbon was a powerful adsorbent and a non-toxic agent for wastewater treatment. The copper, zinc, and methylene blue would be removed effectively by more than 99.2%.

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INTRODUCTION

Wastewater

The skyrocketing of the industrial revolutions has brought positive impacts on the economy. Nevertheless, the drawbacks of industrial activities have worsened, advancing environmental damage, including water pollution. Untreated wastewater discharged from the factory that enters the water body is the primary factor for water pollution. The contaminants, such as heavy metals, dyes, and various inorganic and organic materials that dissolve in non-degradable water have accumulated in the water (Selvie *et al*. 2019; Razak *et al*. 2021). The contaminants usually come from electroplating, chemical manufacturing, metallurgy, mining, and tannery industries (Gutwiński *et al*. 2021; Mariana *et al*. 2021). The pollutants accumulated in the sediments and riverbeds possibly enter the food chain and worsen the water quality consumed by humans and aquatic life (Loska and Wiechula 2003; Yunus *et al*. 2020). Continuous exposure to toxic contaminants, direct or indirect,

can harm humans and marine life. Hence, immediate and preventative action needs to be taken before unwanted accidents happen in the future.

To this day, various types of water treatments have been implemented, including electrochemical treatment, membrane technology, chemical precipitation, solvent extraction, ion exchange, photocatalysis, coagulation, foam flotation, and biosorption (Aris *et al*. 2020; Mariana *et al*. 2021; Razak *et al*. 2021). However, these processes have high risks, such as high cost, toxic residuals, complicated operation, and ineffective removal (Demirbas *et al*. 2004; Dula *et al*. 2014). Because of these risks, researchers have been focusing on finding the best process for wastewater treatment that is cost-effective, environmentally friendly, and has easy operation and high efficiency. As a result, the activated carbon adsorption process has been judged to be the best approach that suits the criteria (Mariana *et al*. 2021). Activated carbon has been recognized especially as one of the best adsorbents for water treatment (Dula *et al*. 2014; Mariana *et al*. 2021).

Activated Carbon

Activated carbon can be described as a black powder, and it is impossible to characterize it accurately using a chemical formula (Cuhadaroglu and Uygun 2008; Yahya *et al*. 2015). Activated carbon is a powerful adsorbent because of its good characteristics, including high surface area, well-developed pore structure, small particle size, and surface-active functional groups (Dula *et al*. 2014; Mariana *et al*. 2021). Commonly, activated carbon is produced from wood, coal, nutshells, and fruit stones (Dula *et al*. 2014). Commercially available activated carbon is expensive. Thus, researchers have been searching for a solution to produce activated carbon at low production cost and high efficiency.

Hassan *et al*. (2022) listed various types of activated carbon produced from agricultural sources as an adsorbent for heavy metals and dyes. Various types of agricultural-based activated carbon recorded excellent removal percentages for methylene blue, rhodamine B, Remazol brilliant blue R, aniline yellow, Pb (II), Co (II), Ni (II), Zn (II), Cu (II), Cd (II), Mn (II), Hg (II), Fe (II), Mg (II), and As (V). Activated carbon from agricultural sources was found to be the best option because of its abundance and inexpensiveness, especially from bamboo plants. Bamboo plant chemical contents were reported as follows: 60.0% to 70.0% of holocellulose, 20.0% to 25.0% of pentosans, 20.0% to 30.0% of cellulose, hemicellulose, and lignin (Razak *et al*. 2021; Yusoff *et al*. 2021). Hence, bamboo is a good starting material for activated carbon production.

Fig. 1. Powdered activated carbon

Adsorption of Contaminants by Activated Carbon

The adsorption process provides an easy application and is effective for wastewater treatments. Moreover, activated carbon (AC) is an excellent adsorbent for the adsorption process of wastewater treatments, disregarding the production method used. Further, the application of activated carbon consumes minimal energy, as it is straightforward to operate. AC produced from agricultural sources and wastes has recently been popular for its low-cost and effective treatments.

Heavy metals in excessive amounts in the water systems are hazardous to humans and aquatics because of their toxic and mobile nature (Kamaruzaman *et al*. 2017; Razak *et al*. 2021). Excess iron and zinc can induce oxidative stress damage and increase one's risk of getting cancer even though these metals are abundant in human bodies (Wang *et al*. 2019; Razak *et al*. 2021). Moreover, over 3 ppm in drinking water, copper metals stimulate gastrointestinal symptoms (Taylor *et al*. 2020; Razak *et al*. 2021). Dyes are occasionally used in bulk for industrial activities such as textiles, paper, rubber, and cosmetics (Liu *et al*. 2020). Excess discarded dyes from industrial wastewater are mostly toxic and obstruct the sunlight from penetrating the water sources (Liu *et al*. 2020). Water pollution caused by dyes can be detected easily because the color of dyes is noticeable.

Liu *et al*. (2020) studied the adsorption of Rhodamine B (Rh B) dyes by activated carbon. The activation process with KOH at 900 °C produced the bamboo-activated carbon. The Rh B dyes are cationic dyes that are advantageous in industrial activities for coloring agents (Liu *et al*. 2020). Based on the study, five factors of the adsorption process were examined, including dosage, contact time, pH, initial concentration, and temperature. The optimum dosage of AC was recorded for 30.0 mg because increasing the dosage of AC from 10.0 mg to 30.0 mg can increase the surface area, pore volume, and an oxygen-containing group that enhances the adsorption process.

Moreover, the process showed a rapid reaction in the first 30 min because of the abundance of active sites in the early process. The percentage of removals slowly increased until the process reached equilibrium within 4 h. In contrast, the pH of the process was tested, ranging from pH 3 to 11. The results recorded that the percentage of removals increased alongside the increasing pH. The findings revealed that at the higher pH value, the negative charge of AC surfaces enhances the electrostatic interaction between negatively charged AC surfaces with the positively charged Rh B ions. The temperature of the process does not affect the adsorption process.

Ghosh *et al*. (2020) studied methyl orange (MO) removals. The focus was contact time, pH value, dosage, and initial concentration. The rapid reduction of the dyes in the first 10 mins can be related to many vacant sites. After that, it slowly reached equilibrium within 2 h after most of the vacant sites were filled. Moreover, pH value plays an essential role in adsorption (Tao *et al*. 2019; Abollé *et al*. 2022). The removal of MO favors the acidic nature rather than the basic solutions. The study conducted by Abollé *et al*. (2022) recorded that the removal of MO dyes increased from 52.09% to 99.75% as the pH value decreased from 11.61 to 2.04. The two will repel each other because MO is an anionic dye, and the AC surface has negative charges. Then, the surface modification of AC is needed.

The study conducted by Ghosh *et al*. (2020) showed that the optimum pH value for MO removals was pH 3. This phenomenon can be related to the protonation process of the AC surface and changing it into positive charges. Then, the Van der Waals interactions and electrostatic attraction between the negative ion in MO dyes and the positive charge on AC surfaces attracted and increased the MO removals. The AC dosages significantly impact the percentage of deductions from 34.0% to 98.0% after the dosages increase from 1 to 30

g/L. The higher percentage of removals influenced the excess available unsaturated active sites.

Moreover, the initial concentration of the dye solution also affects the rate of reductions where at 10 to 100 ppm, the reductions increase, and the further increase of the initial dye concentration will decrease the percentages of removals. It can be concluded that a low concentration (10 to 100 ppm) boosts the significant driving force to transfer a high mass of MO from the liquid to the solid phase in aqueous solutions. It was observed that when the initial concentration was increased further, the removals were decreased because the active sites became filled with MO dyes and excess MO dyes remained unabsorbed in the solution.

A study by Lo *et al*. (2012) on the removals of heavy metals, including Pb, Cu, Cr, and Cd, confirmed that the critical factors for the adsorption process are pH, contact time, and dosage. The initial process showed that the percentages of removals increased with increasing pH and later decreased as the pH increased after the maximum removals were achieved. The optimal pH value for removing heavy metals ranges from 7.10 to 7.83. The adsorption of heavy metals showed a rapid reduction for the first 4 h and finally reached an equilibrium state in 24 h. The adsorption efficiency increased with a higher amount of AC dose. The adsorption process went smoothly because of the negative surface of AC that attracted the positive charge in metal ions.

Table 1. Removal of Pollutants by Activated Carbon

AC Sources	Method of AC Production	Parameters	% Removal	References
Bamboo (China)	Chemical activation using KOH	Dosage: 30.0 mg Time: 4 h pH: 7 Temperature: 25 °C	Rh B: 387 mg/g	(Liu *et al*. 2020)
Mahagoni bark (Bangladesh)	Chemical activation using NaOH	Dosage: 10.0 g Time: 2 h pH: 3.0 Temperature: 25 °C	MO: 92.0%; 6.071 mg/g	(Ghosh *et al*. 2020)
Bamboo (Taiwan)	Chemical activation using deionized water	Dosage: 0.5 g Time: 1 h pH: 7.10 – 7.83 Temperature: 25 °C	Pb (II): 98.8% Cu (II): 93.5% Cr (III): 91.7% Cd (II): 87.8%	(Lo *et al*. 2012)

Note: KOH: Potassium hydroxide, NaOH: Sodium hydroxide, Rh B: Rhodamine B, MO: Methyl orange, Pb: Lead, Cu: Copper, Cr: Chromium, Cd: Cadmium

Bamboo Plant

Bamboo is part of a group of the grass family that have a large woody culm. There are 1662 species, including 121 genres that potentially substitute for traditional construction materials such as wood and steel (Javadian *et al*. 2019; Borowski *et al*. 2022). A bamboo plant can be illustrated as a long cylindrical rod connected by a stem, generally known as a culm. Bamboo anatomy incorporates nodes, internodes, and diaphragms, and the species can be determined according to its types of root systems: sympodial, monopodial, and amphodial (Sharma *et al*. 2015; Awalluddin *et al*. 2017). Compared with wood, bamboo is a lightweight material with good physical and mechanical features, making it a versatile material for natural fiber in manufacturing (Yusoff *et al*. 2021).

Fig. 2. *Gigantochloa albociliata*

Bamboo serves various benefits and applications as an economical agricultural material and source, as it has over 1000 types of bamboo in cultivation worldwide and is suitable for all climate conditions (Rao *et al*. 2020; Borowski *et al*. 2022). The growth rate of these gigantic plants takes less time, approximately 3 to 5 years, compared to other timber materials and naturally developed forests. Bamboo is considered a fast-growing plant and is readily available throughout the country, making it a scalable material suitable for the bulk production of activated carbon. Interestingly, the bamboo forest can absorb a generous amount of CO_2, which is three times better than other plants (Emamverdian *et al*. 2020; Borowski *et al*. 2022). Hence, it helps to balance the CO_2 amounts in the surroundings, and it discharges 30% extra O_2 gas compared to other plants (Laidler 2003; Borowski *et al*. 2022).

The activated carbon produced from local bamboo plants by chemical activation with KOH can be produced at a lower activation temperature and conserve energy. Furthermore, activated carbon that is produced has multiple uses for effectively removing both heavy metals (Cu and Zn) and dyes (methylene blue and methyl orange). The bamboo-based activated carbon produced at 500 ℃ showed unique surface morphology and surface-active functional groups. Hence, cheaper and high-quality activated carbon is produced from local bamboo waste. As such, agricultural sources, such as local bamboo plants, can be a better alternative material to produce activated carbon.

METHODOLOGY

The AC sample was produced as described in the following scheme (Fig. 3). It was then used to study the removal of heavy metals and dyes using the procedures stated below (Fig. 4). Finally, the highest removal of activated carbon sample was used to determine the surface functional groups present and surface morphology.

Sample Preparation

The bamboo sample of *G. albociliata* was collected and cleaned with tap water before being dried in the vacuum oven at 50 ℃ for a week. The dried bamboo was chopped into smaller parts, including the bottom, middle, and top. Bamboo was divided according to each part and proceeded to the pre-carbonization process in a muffle furnace. The carbonization process is performed primarily to decrease the volatile matter contained in

the sample (Liu *et al*. 2020). The carbonization took about 1 h to completely turn bamboo into charcoal at 350 ℃. The bamboo charcoal formed was air-dried and then cooled to room temperature. The bamboo charcoal was ground into a fine powder using a mortar and pestle and stored in a vacuum oven to avoid moisture. The temperature of the vacuum oven was set at 50 ℃.

Activation Process

The bamboo charcoal powder was activated using KOH as an activating agent. The charcoal powder was mixed with KOH at a 1:1 ratio and agitated overnight. The mixture temperature was set at 50 ℃ for the first 5 h and at room temperature for the rest. The mixture was filtered using a Buchner funnel, and the solid charcoal was collected. The solid charcoal was pyrolyzed for the second time using a muffle furnace. Two different temperatures of the muffle furnace were set, which were 500 and 600 ℃. Activated carbon produced was labeled with its initial part and temperature, such as B5, B6, M5, M6, T5, and T6.

Fig. 3. Activated Carbon Production

Removal Process

The removal studies were conducted with two types of heavy metals (copper and zinc) and dyes (methylene blue and methyl orange). The preliminary study of the removals process was conducted with Cu and Zn metals ions and MB and MO dyes with different parameters. Cu and Zn ions used in this work represented heavy metals, since the great majority of heavy metals, in their most toxic form, are positively charged metal ions. Then, activated carbon samples produced were used to determine the heavy metals and dyes removal by using the best parameter from the preliminary study. The aqueous sample solution for both Cu and Zn metals was prepared at 20 ppm concentration, whereas MB and MO dyes were prepared at 200 ppm. The actual sample concentration was determined before and after the adsorption process.

1.0 g and 2.0 g of activated carbon samples were added to the metals and dyes solutions. The pH of aqueous solutions was fixed at pH 7 for metals (Cu and Zn), pH 10 for methylene blue dye, and pH 3 for methyl orange dye. The mixture of the solutions containing the activated carbon sample was agitated, and the solution was allowed to equilibrate for 20 hours. The temperature of the solution was kept constant at 50 ℃ in the course of the removal process. Lastly, the sample solutions were filtered, and the final concentration was analyzed using atomic absorption spectroscopy (AAS) for heavy metals and ultraviolet-visible spectroscopy (UV-vis) (Fig. 4).

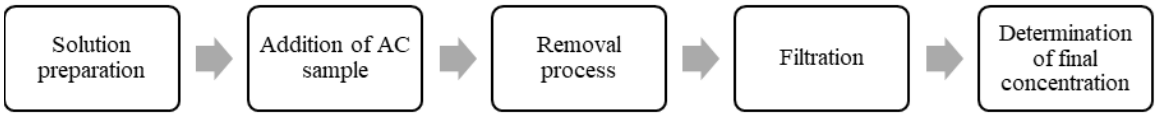

Fig. 4. Removal process of heavy metals and dyes from aqueous solutions

Characterization of Activated Carbon

Analysis of surface functional groups of the activated carbon produced was carried out. Fourier-transform infrared spectroscopic (FTIR) analysis (Perkin Elmer, Frontier, Waltham, MA, USA) was used to determine the functional groups present on the sample surfaces. Hence, the hints of the possible interaction that will occur were predicted. The possible type of functional group present was determined by scanning in the range of 4000 to 600 cm^{-1}.

Besides, the surface morphology of the activated carbon was studied by using scanning electron microscopy (SEM, Jeol Ltd., Tokyo, Japan). A small amount of powder-activated carbon sample was placed onto the thin glass film plate. The magnification of 5,000× was employed, and the images of the pores of the AC were captured.

RESULTS AND DISCUSSION

Preliminary Study of the Removal Process

Parameters that affect the adsorption process

Apart from the starting material of AC used, the removal process can be affected by various parameters, including adsorbent dosage (Tao *et al*. 2019; Shah *et al*. 2020), contact time (Muslim 2017; Tao *et al*. 2019; Shah *et al*. 2020), pH value (Tao *et al*. 2019; Shah *et al*. 2020), and temperature (Shah *et al*. 2020). Hence, the selected AC sample was used to determine the optimized conditions for the adsorption process.

Adsorbent dosages

The amounts of AC sample added into the solution were 1.0 g, 2.0 g, and 3.0 g for 20 h of contact time. The results showed that the lowest effective dosage was 1.0 g, and 2.0 and 3.0 g both showed very high percentage removals (Table 2). As expected, the lower percentage removal for the 1.0 g sample was attributed to the low active sites of the AC surface that were available for the adsorption process. However, there was no significant difference between 2.0 and 3.0 g removals for Cu metal and MB dye. Hence, the optimal adsorbent dosage was judged to be 2.0 g. For MB dye, 3.0 g of AC added showed slightly lower removals than 2.0 g because the adsorption process already achieved an equilibrium state and caused the percentages of removals to decrease slightly. For MO dye, 3.0 g of AC increased the removals from 82.69% to 90.51%. Three grams of AC provides more vacant active sites for MO removals, thus increasing the reduction percentage.

Table 2. Effects of Activated Carbon Dosage on the Adsorption Process

Contaminants	Percentage Removal (%)		
	1.0 g	2.0 g	3.0 g
Cu	28.7	98.1	**98.5**
MB	95.9	**98.7**	98.3
MO	39.2	82.7	**90.5**

Contact time

The contact time for the adsorption process was examined at 5 h, 10 h, and 20 h. The high availability of vacant active sites on absorbent surfaces drove the fast reaction during the early times of the adsorption process. After certain times, most of the vacant sites were occupied, and the reaction became slow and reversible due to the repulsive force

among the solute molecules on the solid and bulk phases (Mohan *et al*. 2006; Dula *et al*. 2014). The percentage of removals slowly increased and finally reached equilibrium within 20 h of the reaction (Table 3).

The percentage removals of Cu were slightly decreased from 10 to 20 h of the reaction because the reaction attained a saturated state and achieved equilibrium. It is noted that the percentage removals of the MO dyes showed a slow trend because of the repulsive force that builds between the anionic dye and the negative surface of the AC (Dula *et al*. 2014; Hii 2021). Due to the protonation of the AC surfaces after the pH adjustment, the percentage removals of MO dyes finally increased to 82.7%.

Table 3. Effects of Contact Time on the Adsorption Process

Contaminants	Percentage Removal (%)		
	5 h	10 h	20 h
Cu	99.1	**99.5**	99.2
MB	98.5	98.1	**98.7**
MO	55.1	53.2	**82.7**

pH value

The pH value of the solution was tested at 3, 7, and 10 during the adsorption process. The AC surface activated by KOH most likely was negatively charged, as referred to in the FTIR spectra (Figs. 5 and 6) (Mariana *et al*. 2021). Hydroxyl and carbonyl groups help the cationic molecules attract to the adsorbent surfaces at higher pH values (Wang 2017; Kuang *et al*. 2020). However, at a low pH value, the abundance of H^+ ions and metal ions in the solution competed to react with the adsorbent active surface (Lalhruaitluanga *et al*. 2011). This leads to higher adsorption as the pH value increases from 7 to 10 because the low amounts of H^+ ions are at a higher pH value for cationic ions of Cu metal and MB dye.

Based on Table 4, the percentage of removals of Cu metals increased when the pH value increased from 3 to 7, and a further increase of the pH to 10 caused the removal percentage to decrease. The percentage of removals decreased along with the increased pH value after the maximum adsorption capacity was reached (Lo *et al*. 2012), which showed that the optimal pH value for Cu removals was pH 7. Meanwhile, for methylene blue, the cationic dye adsorption showed a slightly higher removal percentage when the pH increased from 3 to 10 (Kuang *et al*. 2020). Hence, the optimal pH value for methylene blue was judged to be pH 10.

Methyl orange is an anionic dye that carries more negative ionic charges than positive charges. A lower pH solution causes the AC surfaces to become positive because of the protonation, thus leading to the combination of both Van der Waals interaction and electrostatic attraction of the negative molecules of methyl orange dyes and the positive charge of AC surfaces (Ghosh *et al*. 2020). This explains why at pH 3 the percentage of removals of methyl orange was higher than that at pH 7 and 10.

Table 4. Effects of pH Value on the Adsorption Process

Contaminants	Percentage Removal (%)		
	pH 3	pH 7	pH 10
Cu	11.6	**99.2**	63.9
MB	77.8	98.4	**98.5**
MO	**74.7**	73.1	23.6

Temperature

The temperature of the adsorption process was studied at 25, 50 and 80 ℃. The data indicate a slightly higher removal percentage at 50 ℃ than at room temperature. This increase might be driven by the dye molecules greater mobility and the rise in the number of active adsorption sites at higher temperatures (Güneş and Angın 2021). This finding is in accordance with Dula *et al*. (2014) where the percentage of removals increased by 1.37% (from 97.0% to 98.4%) when the temperature increased from 25 to 45 ℃. Active adsorption sites increased at high temperatures due to bonds breaking in functional groups, potentially resulting in improved adsorption (Dula *et al*. 2014). Nevertheless, the increased temperature to 80 ℃ for the dye molecules caused the bonds of ions and AC surfaces to break because the molecules of dyes are bulkier compared to metal ions.

Table 5. Effects of Temperature on the Adsorption Process

Contaminants	Percentage Removal (%)		
	25 °C	50 °C	80 °C
Cu	97.9	99.2	**99.2**
MB	98.7	**98.7**	98.2
MO	74.2	**82.7**	71.0

Removal of Heavy Metals and Dyes by Activated Carbon

The experiments in which AC sample removed heavy metals (Cu and Zn), and dyes (methylene blue and methyl orange) were conducted as follows. The metal solutions with an initial concentration of 20 ppm and the dyes solution of 250 ppm were first prepared accordingly. About 1.0 g and 2 g of AC sample were added to the solutions and heated at 50 ℃. After 20 h, the mixture solutions were filtered using Whatman filter paper until there were no solids seen. The percentage removals of the contaminants were determined using AAS analysis for heavy metals and ultraviolet-visible spectroscopy (UV-Vis, Shimadzu, Kyoto, Japan) for dyes.

An excellent result for the adsorption of Cu and Zn metals was shown for 2 g of AC. The results were as expected because 2 g of AC provides more vacant sites for the adsorption of the metal ions, leading to higher removals compared to the 1.0 g sample. Moreover, the high removals percentage can be explained by the negative surfaces of AC that easily bind with the positive charges of metal ions. The highest percentage of removals of Cu ions was 99.3% by B6, and Zn ions were 99.6% by the M6, respectively.

The adsorption of dyes showed a slightly different trend compared to the metals. Dyes molecules are slightly bigger compared to metal ions. The highest percentage of removal of the dyes was lower than that of metals. The adsorption removals for methylene blue were slightly higher than those for methyl orange due to the different charges each dye sample carries. Methylene blue is a cationic dye (Sahu *et al*. 2020) and methyl orange is an anionic dye (Abollé *et al*. 2022). The negative surface of AC can bind easily with positive charges of methylene blue dyes, while it repels the negative charges that methyl orange carries. Based on the results, the highest percentages of methylene blue and methyl orange removals were 99.2% by T6 and 89.2% by M5.

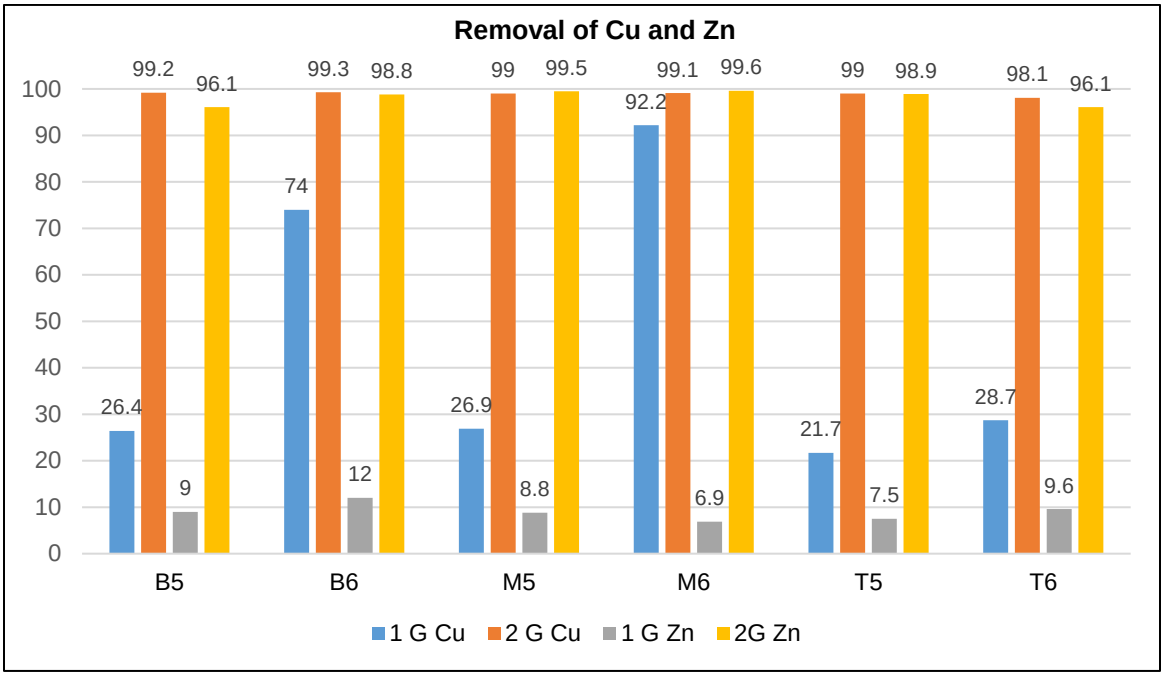

Fig. 5. Removal of Cu and Zn by activated carbon

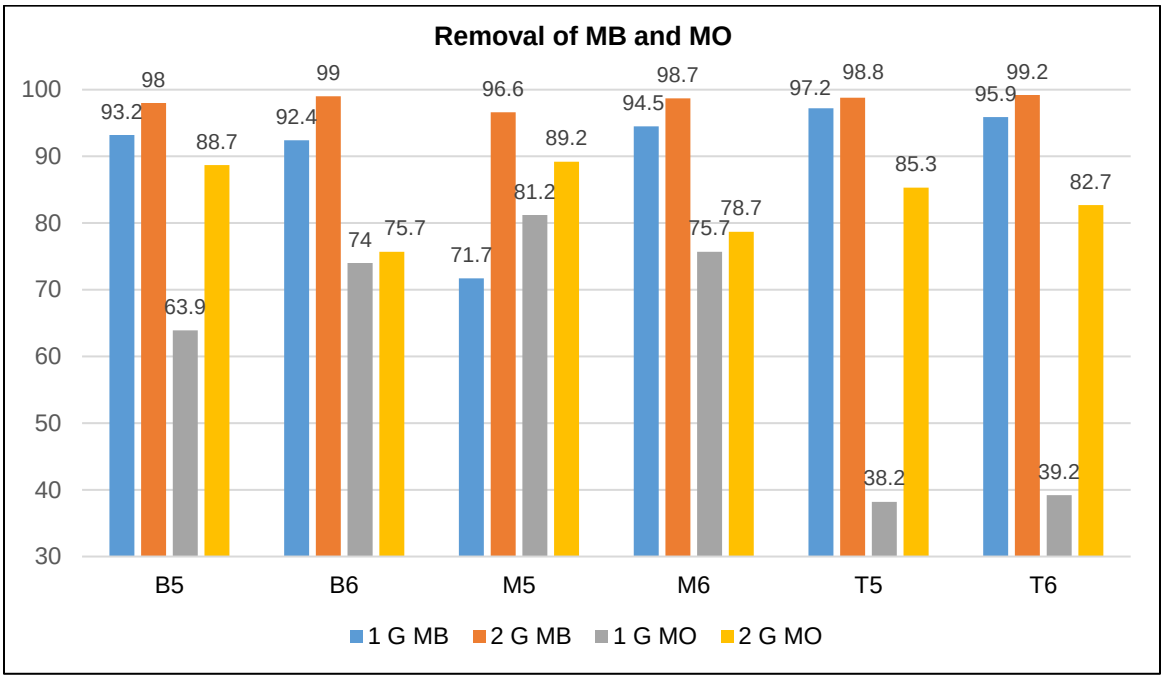

Fig. 6. Removal of methylene blue and methyl orange by activated carbon

The result showed no significant difference between each part of bamboo used to produce the activated carbon sample. All bamboo parts (bottom, middle, and top) showed equally high percentages of removals for both heavy metals and dyes.

Fourier Transform Infrared Spectroscopy Analysis

Based on the IR spectrum of AC before the adsorption process, there was no significant difference between the sample produced at 500 and 600 ℃ (Figs. 7, 8, and 9). Broad peak vibration of OH groups showed within the range of 3600 to 3000 cm^{-1} and stretching vibrations of C≡C groups of alkynes were found at 2300 to 2100 cm^{-1}. The stretching vibrations of C=O, C=C, and C-O can be observed at 1732 to 1480 cm^{-1}, 1480 to 1228 cm^{-1}, and 1228 to 976 cm^{-1}, respectively. The existence of these functional groups helps to enhance the adsorption process of the contaminants onto the surfaces of AC samples (Dula *et al*. 2014).

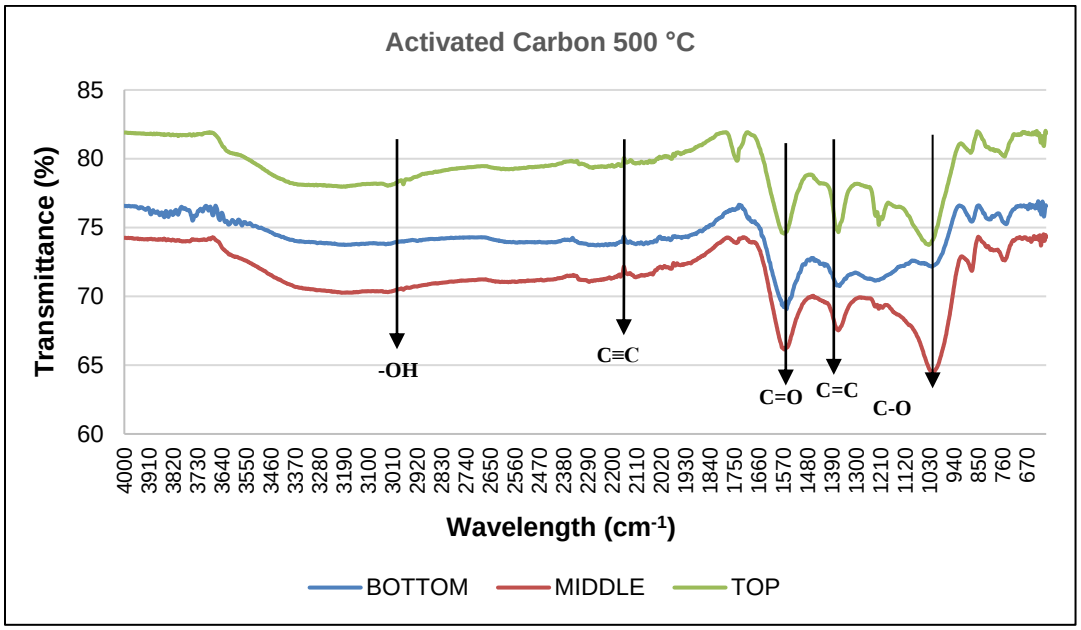

Fig. 7. IR spectrum for activated carbon produced at 500 °C

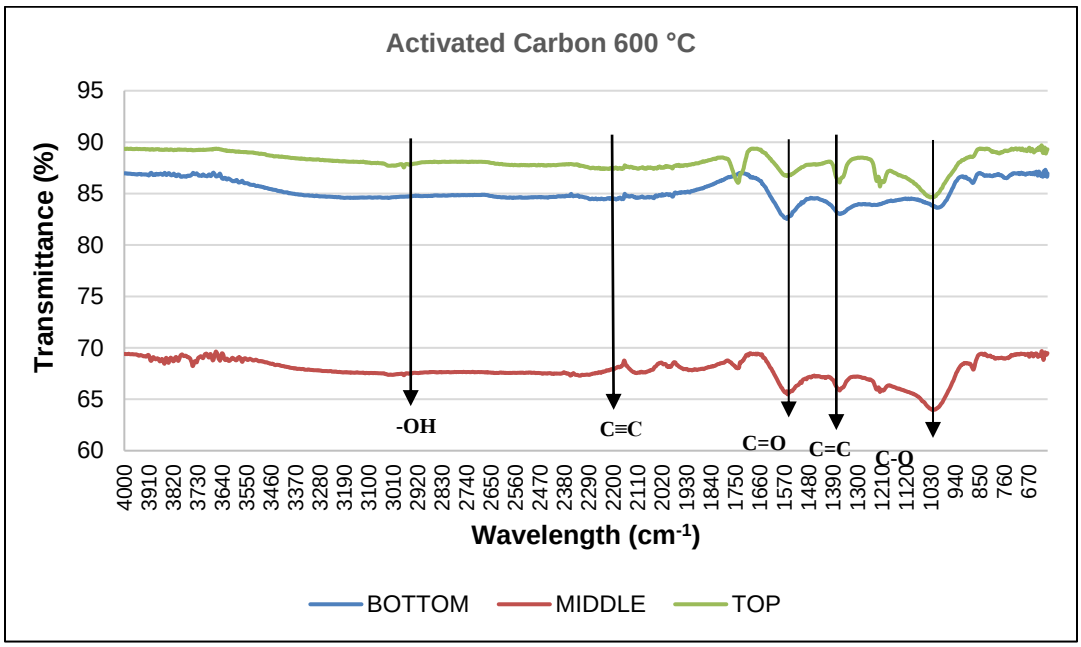

Fig. 8. IR spectrum for activated carbon produced at 600 °C

A random sample was chosen after the adsorption process and tested to check for any difference in the IR spectrum before and after the adsorption process. From the IR spectrum, a slight shift can be seen in the transmittance (%) value. The peaks that indicated the functional groups present do not show any noticeable difference before and after the adsorption process. The AC sample before the adsorption process showed the lowest transmittance % followed by the samples of AC after the removals of MO, MB, and Cu is the highest.

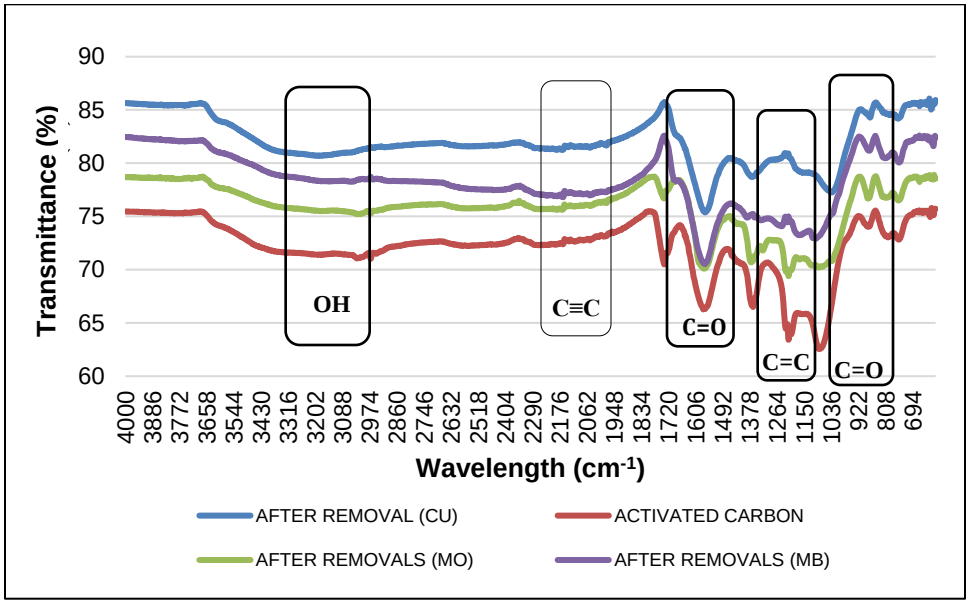

Fig. 9. Comparison of activated carbon samples before and after the adsorption process

The IR spectrum images studied by Dula *et al*. (2014) showed that the percent transmittance after the removal of Cr (IV) was higher than that before the removal process. The findings are supported by Shah *et al*. (2020), where the transmittance % of the samples after removal was higher than before. Further, Sawasdee *et al*. (2020) also reported that the transmittance % of the IR spectrum increased after the removal process. Hence, this verified that there was an interaction between the contaminants and the active surface of the AC sample (Dula *et al*. 2014).

Scanning Electron Microscope Analysis

The porosity developments on the surface of the AC sample are highly affected by the starting materials, activation method, activating agents, and impregnation ratio. Moreover, the starting materials are essential in developing the porous structure on the AC surfaces (Yahya *et al*. 2015; Yusoff *et al*. 2021).

Based on the SEM images (Figs. 10 through 12), the surfaces of bamboo charcoal (Fig. 10) that undergo the pre-carbonization process at 350 ℃ showed very limited pores. However, after the activation process with KOH at 500 ℃, the pores on the AC surfaces could be seen clearly, as shown in Fig. 11, compared to that of bamboo charcoal (Fig. 10a**)**. The carbonization process at higher temperatures caused the decomposition of cellulose, hemicellulose, and lignin and the release of volatile compounds (Liu *et al*. 2020). However, the activated carbon activated at 600 ℃ showed some cracked surface pores. This might be due to the temperature higher than 500 ℃ being incompatible with the pore

developments. Moreover, an excess presence of the unsymmetrical pores on the surface of the AC was contributed by the chemical reaction with KOH during the activation process (Basta *et al*. 2009; Liu *et al*. 2020). The porous surfaces help trap the contaminants onto the AC surfaces and increase the efficiency of the adsorption process (Ghosh *et al*. 2020).

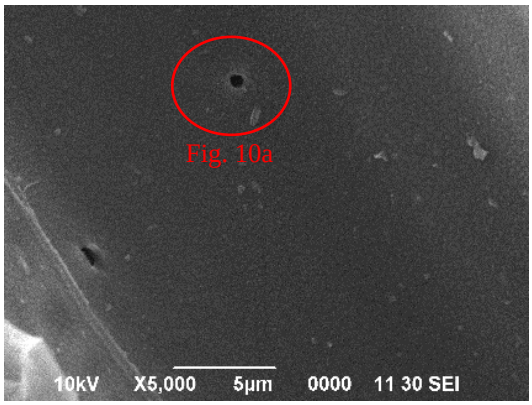

Fig. 10. SEM Image of Bamboo charcoal

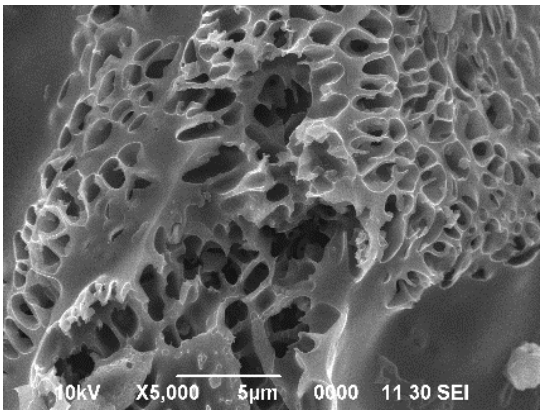

Fig. 11. SEM Image of AC at 500 °C

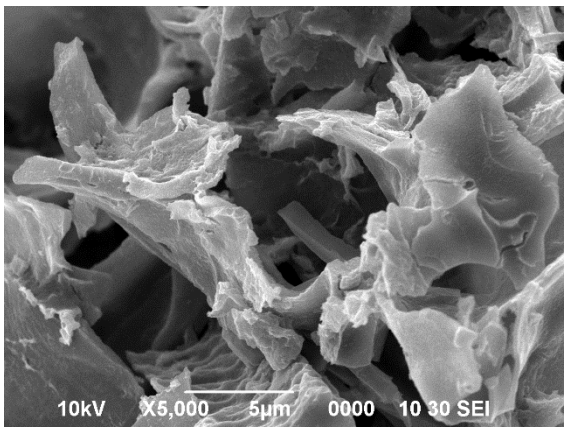

Fig. 12. SEM Image of AC at 600 °C

CONCLUSIONS

1. The bamboo charcoal derived from *Gigantochloa albociliata* was activated at different temperatures with KOH, as an activating agent, in the muffle furnace to produce the activated carbon.
2. The activated carbon surfaces were shown to be negatively charged, as indicated by carbonyl groups in the IR spectrum. The SEM images captured at 5000× magnification also proved the appearance of unsymmetrical pores that helps in enhancing the adsorption process.
3. Heavy metal removals are enhanced by optimizing the adsorbent dosages, contact time, temperature, and pH value of the adsorption process.
4. An optimized condition of the adsorbent dosages was recorded for 3.0 g for both Cu and methyl orange and 2.0 g for methylene blue. The best contact time for the adsorption process was judged to be 10 h for Cu removals and 20 h for methylene blue

and methyl orange, respectively. Meanwhile, pH 7 was the best-fit pH value for Cu, methylene blue was pH 10, and pH 3 was for methyl orange. Lastly, the most favorable temperature for removal of each contaminant was 80 ℃ for Cu and 50 ℃ for the dyes.

5. The highest percentage removals recorded for Cu, Zn, methylene blue, and methyl orange were 99.29%, 99.59%, 99.18%, and 89.22%, respectively.
6. The findings verify the feasibility of providing a cheap, sustainable, and effective alternative adsorbent material for water treatment from local bamboo, which will undoubtedly improve the quality and sustainability of life for humankind and is in line with the pursuit of green growth for sustainability and resilience and contributes towards the Sustainable Development Goals.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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