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Enhance the Quality of Medical Liquid Waste via Agitation Utilizing Hydrochloric Acid Activator in Conjunction with Bamboo Activated Carbon

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Abstract

The proper treatment of medical waste, which originates from various medical procedures, plays a vital role in protecting the environment and promoting human health. One potential strategy for improving the quality of medical waste is the utilization of the adsorption process for the goal of purification. The implementation of a biomass-derived activated carbon medium can enhance the execution of this technique. The aim of this study is to investigate the changes in the morphological and chemical properties of activated carbon derived from Gigantochloa apus (GA) and Bambusa vulgaris (BV) after being exposed to medical waste. The chemical activation technique is performed using a hydrochloric acid (HCl) solution with a concentration of 0.1 M. The length of the drying procedure has an impact on the surface properties and pore development of activated carbon, which has the potential to enhance its capacity for adsorbing chemicals in liquid medical waste. There exists a positive association between the length of agitation and the pH value, resulting in an augmentation of ion absorption. The activated carbon known as BV exhibits a greater carbon content in comparison to GA activated carbon, resulting in a reduction in Total Dissolved Solids (TDS) within treated wastewater. The phenomenon of agitation serves to promote the contact between the adsorbent and adsorbate, hence leading to the reinforcement of Van der Waals forces. BV exhibits a greater absorption capacity in comparison to GA.

1. Introduction

The Bambusoideae family is characterized by its wide range of big, woody grasses, consisting of more than 1250 species that are found in 75 different genera worldwide [1],[2]. This chemical is utilized in several industries, including paper manufacture, textile production, board production, food processing, fuel production, and building, with the aim of improving structural integrity [3].

In Indonesia, a nation renowned for its abundant bamboo resources encompassing 76 species from 17 genera, bamboo is widely employed in many purposes including furniture manufacturing, wall repair, construction facades, and wall ornamentation [4]. Bamboo scaffolding is categorized as a building support structure mostly consisting of pliable, non-inert materials. These materials frequently experience contamination from various contaminants, hence making them inappropriate for recycling or reclamation objectives. A

proposed approach for transforming this specific type of trash into a higher-value product, such as activated carbon for wastewater treatment, has been proposed in previous studies [5],[6].

The primary distinction between bamboo activated carbon and other forms of active carbon, such as coal, hardwood, or coconut shell activated carbon, depends on the source of the raw material and its inherent characteristics [7]. Bamboo exhibits a tendency to generate active carbon with a smaller and more uniform pore structure, resulting in superior adsorption properties against a wide range of contaminants, including colors, smells, and other organic compounds, when compared to alternative forms of active carbon. Furthermore, bamboo-activated carbon is seen more sustainable due to the rapid growth rate of bamboo, surpassing that of wood or coal [8][9]. The selection of activated carbon type is contingent upon the requirements of the application and environmental factors. Bamboo-derived activated carbon is a favorable option for environmentally sustainable applications that need certain adsorption properties.

The utilization of the adsorption approach is becoming increasingly prominent in the sector, primarily owing to its flexible operational and design procedures. Furthermore, this technique has a noteworthy impact on several aspects, such as the toxicity, biological availability, and transport of heavy metals in wastewater [10],[11],[12]. The enhancement of the approach's efficacy is contingent upon the creation of a highly effective adsorbent. During the phenomenon of adsorption, contaminants are attracted and attached to a solid surface mostly by physical forces, occasionally aided by weak chemical interactions. When a solution containing a solute that has the potential to be absorbed encounters a solid material with a highly porous surface, the intermolecular interactions between the solute molecules and the solid surface facilitate the absorption or deposition of some solute molecules onto the solid surface [13]. The term "adsorbate" is used to describe a material that has been attached to a solid surface, whereas "adsorbent" refers to the solid surface itself to which the adsorbate is bound [14].

Numerous adsorbents produced from bamboo have been created by researchers, including bamboo-activated carbon [15],[16], bamboo biochar [15],[17],[18],[19], and bamboo aerogel [5],[20],[21], among other instances. To optimize the adsorption rate, it is crucial for a suitable absorbent to exhibit a porous structure that is distinguished by a significant surface area. Furthermore, it is important to reduce the period necessary to achieve adsorption equilibrium. This will facilitate the prompt elimination of contaminants. The efficiency of adsorption in removing contaminants is influenced by various factors, such as temperature [22], the properties of the adsorbent material [23], the presence of other contaminants [24], and experimental conditions and parameters like pH, concentration of pollutants, contact time, particle size, and temperature. Activated carbon is extensively employed in many applications owing to its high adsorption capacity [25], presence of active functional groups [26], large surface area [27], porous structure [25], surface reactivity [27], inert properties [28], and thermal stability [29]. Activated carbon possesses several noteworthy benefits, such as reduced operational costs, a considerable surface area, remarkable stability, and the capacity to modify both surface and structural characteristics. Consequently, bamboo has the capacity to efficiently eliminate toxins and impurities from wastewater.

The current investigation employed locally accessible bamboo species, namely BV and GA, as the principal raw materials for the manufacturing of charcoal. The bamboo charcoal (BC) underwent a chemical modification procedure by the utilization of HCl activation. The modified activated bamboo charcoal used in the study was labeled as BV and GA. The qualities of boundary value and geometric analysis are characterized by important criteria such as consistency, surface shape, and surface area. The effectiveness of biological ventilation (BV) and granular activated carbon (GA) in the treatment of wastewater at the medical faculty was evaluated.

2. Materials and Method

2.1 Materials

The acquisition of GA and BV, a precursor, was achieved through the procurement from a local crofter in Malang, East Java, Indonesia. The proximal analysis of GV and BA is provided in Table 1. The material's low ash content and high concentration of volatile matter indicate that the resultant carbonaceous GA and BV structure possesses favorable characteristics for the manufacture of activated carbon (AC). Table 1 also displays the comprehensive study of final and component. Furthermore, the HCl employed in the experimental protocols was obtained from Merck, especially of analytical grade.

2.2 The Proximate Analysis

The moisture content of charcoal was determined by weighing 1.00 g of BC (Mettler Toledo) during the quality testing process. Subsequently, the sample was subjected to thermal treatment in a furnace (Nabertherm), precisely maintained at a temperature of 105 °C, for a duration of 1 hour. The cup was extracted, chilled within a desiccator, and measured in terms of weight. The water content is quantified as a percentage using the following formula [30]:

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$$\%\ Moisture\ content = \frac{loss\ in\ weight}{weight\ of\ sample\ taken} \times 100 \quad (1)$$

The subsequent characteristic is the volatile matter content, determined by measuring the weight of a moisture-free powder sample and subjecting it to heating in a covered crucible within a furnace at a temperature of 950 °C for a duration of 7 minutes. Subsequently, the specimen is chilled within a desiccator and measured in terms of weight. Subsequently, the proportion of unstable substances in the combustible constituents of the specimen may be ascertained. To ascertain the ash content, the residue remaining after combusting 1.00 g of pulverized charcoal with a certain mass is collected from an open container. This combustion process takes place in a furnace at a temperature of 750 °C until a consistent weight is attained. Last, the proportion of fixed carbon is obtained by subtracting the combined percentage of moisture, volatile matter, and ash from 100.

2.3 The Process of CA Synthesis

The synthesis of activated carbon entails the reduction of precursor materials to dimensions approximately measuring 1 × 1 cm. The raw material was subjected to a washing procedure utilizing distilled water, followed by further drying by exposure to air. Following this, the material experienced a process of carbonization, leading to the creation of a trench with a rectangular shape. Subsequently, BV and GA were introduced into the pit and subjected to the application of fire, serving as an initial stage in the production procedure. Afterward, the charcoal sample was subjected to a chilling procedure, which was then followed by the process of crushing. The particles obtained were subjected to the process of milling and thereafter underwent sieving within the range of 125µm to 250µm to get particles with the appropriate particle size. The charcoal was later mixed with 40 ml of HCl solution, having a concentration of 0.1 M. The mass of charcoal used in the experiment was 0.12 grams. Following that, the samples were subjected to agitation at a rotational velocity of 100 rpm for a period of 48 hours. Subsequently, the specimens underwent a drying process in a Sharp oven, where they were exposed to a temperature of 200°C for a duration of 2 hours.

2.4 The Adsorption Process

Prior to commencing the adsorption technique, a combined solution of 40 mL of medical liquid waste, together with activated granular activated carbon (GA) and bituminous virgin (BV) charcoal, was created. Once the two components have been appropriately prepared, they are then combined within a beaker and securely sealed with aluminum foil, serving as a precautionary step for safety. The glass is then agitated utilizing a magnetic stirrer known as Baku, which functions at a rotating velocity of 150 rpm for varying time intervals, specifically 24 hours, 36 hours, and 48 hours, while upholding the ambient temperature. Following agitation, the activated carbon and liquid medical waste are combined, and a designated period of 24 hours is allotted for the sedimentation process. The adsorption process is iteratively conducted until every modification is included.

2.5 Material Analysis

The physical properties of BV and GA were determined using the technical activated charcoal SNI (Indonesian National Standard) [31]. The characteristics cover the percentage of water content, volatile matter content, total ash content, and carbon content. The Shimadzu equipment was utilized to perform Fourier Transform Infrared Spectroscopy (FTIR) (Shimadzu) analysis on the charcoal sample with the purpose of characterizing its functional groups. The elemental composition and morphological evaluations of BV and GA were examined using a field emission scanning electron microscope (FESEM) (FEI Quanta 650), both before to and during the adsorption process. To assess the effectiveness of adsorption as a method for wastewater treatment, measurements of pH and TDS (EZ9909) were performed prior to and during the adsorption process.

3. Results and Discussion

The characterization of the bamboo charcoal was conducted to assess its compliance with several parameters, including water content, ash content, volatile material content and carbon content. The findings are shown in Table 1. Both BC and CA have distinct physical characteristics, as indicated by the statistics presented in Table 1, which are common to both regions. Several criteria must be met to classify a material as activated carbon. These include a water content of less than 15%, an ash content of less than 10%, a volatile substance content of less than 25%, a carbon content of more than 65%, and adherence to the activated carbon standard SNI 06-3730-95.

The characteristics and adsorption efficiency of activated carbon are influenced by its moisture content, wherein higher moisture level results in reduced adsorption capacity. According to the findings, both BC and CA exhibit water content levels below 15%, aligning with the established norms. The residual mineral matter remaining after the process of carbonization is commonly known as ash content. The determination of metal oxides is necessary through ash content analysis due to the utilization of natural raw materials that contain

minerals with carbon molecules. During the process of mineral activation and carbonization, certain minerals undergo loss, while others undergo oxidation with oxygen, resulting in the formation of ash. The carbon content of bamboo charcoal refers to the fraction of carbon that is chemically linked to the substance, excluding any water, ash, and volatile chemicals. The loss of volatile chemicals occurs during the heating process due to the breakdown of active carbon components in carbonization. By increasing the carbonization temperature, it is possible to minimize the presence of volatile compounds. Insufficient temperature and degradation mechanisms can lead to elevated levels of volatile compounds. The quantity of volatile compounds is significantly influenced by the carbonization temperature and duration.

Table 1 *Bamboo charcoal (BC) and activated bamboo charcoal (CA) physical properties*

		Water Content (%)	Ash Content (%)	Volatile Substance Content (%)	Carbon Content (%)
BV	BC	7.43	7.21	11.82	73.54
	CA	7.13	5.46	11.31	76.10
GA	BC	6.71	6.21	10.11	76.97
	CA	6.66	4.56	8.74	80.04
SNI [31]		Max 15	Max 10	Max 25	Min 65

Table 2 *FTIR spectra of CA*

Type Of Bamboo		Functional Group	C-H (Strong)	C-O	C=C
wave number (cm^{-1})	BV	BC	869.99	1028.10	1570.26
		CA	673.17	1029.72	1571.69
	GA	BC	874.27	1052.54	1571.69
		CA	872.84	1031.15	1554.57

The investigation of FTIR spectra revealed an observed augmentation in the intensity of absorption within the wave number range of 3500–2700 cm^{-1}, which corresponds to the absorption zone associated with the hydroxyl group. It is worth mentioning that the activated bamboo charcoal exhibited the highest level of intensity throughout the region. The enhanced absorption intensity within the wave number range of 3000-2700 cm^{-1} demonstrates the synthesis of aromatic chemicals. As indicated in Table 2, the hydroxyl groups attached to C-H exhibit strong stretching vibrations (690-900 cm^{-1}), which are characteristic of methylene and methyl groups. Additionally, the presence of C-O stretching vibrations (1050-1300 cm^{-1}) is evident. Vibrations observed at 1500-1600 cm^{-1} correspond to the stretching vibrations of C=C bonds in carboxyl, lactone, aldehyde, and ketone compounds. Activated bamboo charcoal's functional groups are not eliminated by the activation process, according to the information in Table 2. These functional groups lined up with the typical functional groups of activated carbon and acted as the adsorption process' active sites. Fig. 1 illustrates the findings of the liquid waste pH test. At a drying temperature of 200°C, BV caused the pH increase that was largest, and GA produced the pH increase that was lowest, both with a 48-hour agitation period. With longer periods of agitation, the pH value seems to lean toward rising.

Variations in pH levels can arise from variations in drying duration, since this influences the quality of the surface and the number of pores generated. Enhanced surface quality and increased pore count can augment the capacity of activated carbon to absorb or absorb the substrate or adsorbate present in liquid medical waste. The extension of the agitation time appears to suggest a positive correlation with the pH value, as a lengthier agitation period leads to a greater absorption of ions from the liquid medical waste by the activated carbon. Consequently, this absorption process results in an elevation of the pH level inside the waste. This observation aligns with the findings presented by Budiharjo et al. (32), wherein they assert that the quantity of adsorbent exposed to adsorption is contingent upon the duration of agitation employed in the adsorption procedure, thereby leading to an elevation in the pH level of liquid medical waste.

As seen in Fig. 2, an increase in the time of agitation leads to a corresponding drop in TDS value. This phenomenon arises due to the positive correlation between the duration of agitation and the duration of contact between the adsorbate and the absorbent. Consequently, this extended contact period enhances the probability of adsorption of the adsorbate by BV and GA active carbon. The extent of adsorption between the adsorbent and adsorbate is directly proportional to the duration of the adsorption period. As the adsorption period lengthens, more adsorbate molecules are absorbed onto the adsorbent surface, resulting in an increase in the adsorption capacity. This trend continues until the system achieves equilibrium, as indicated by previous research [33].

The TDS value exhibited a more pronounced drop after the application of agitation with both BV and GA activated carbon. Hence, the presence and dimensions of pores will exert an influence on the efficacy of activated carbon in sequestering the solid substrates and adsorbates present in liquid medical waste. Like previous findings, BV activated carbon exhibits a higher carbon content compared to GA activated carbon. In the context

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of medical wastewater treatment, it has been shown that the utilization of activated carbon derived from BV as opposed to GA leads to a reduction in the concentration of TDS in the treated wastewater.

Fig. 3 displays the outcomes of SEM-based morphological examination. This graphic displays pictures of the pores in BV and GA activated carbon in situations before activation, after activation, and after adsorption. According to the SEM results in Figure 3 for both GA and BV at a magnification of 5000 times, the AC possesses morphology that is more porous than BC. Its analysis was performed to evaluate the morphological traits of BC and AC to spot any changes. According to the SEM findings, BC has initially closed pores. Activation, however, makes it clear that the pores are starting to widen more. Whether chloride acid is utilized as the activator has no bearing on this result.

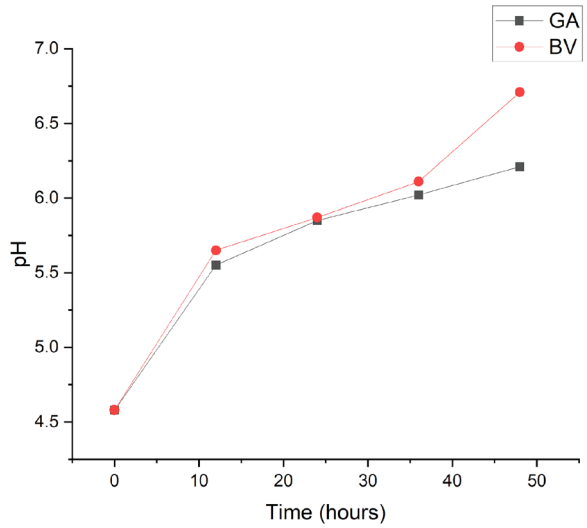

Fig. 1 *The level of acidity in the waste solution*

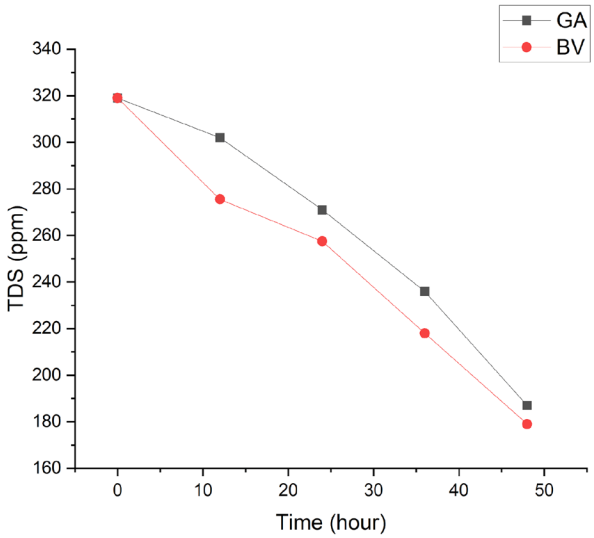

Fig. 2 *Dissolved substances in the waste solution*

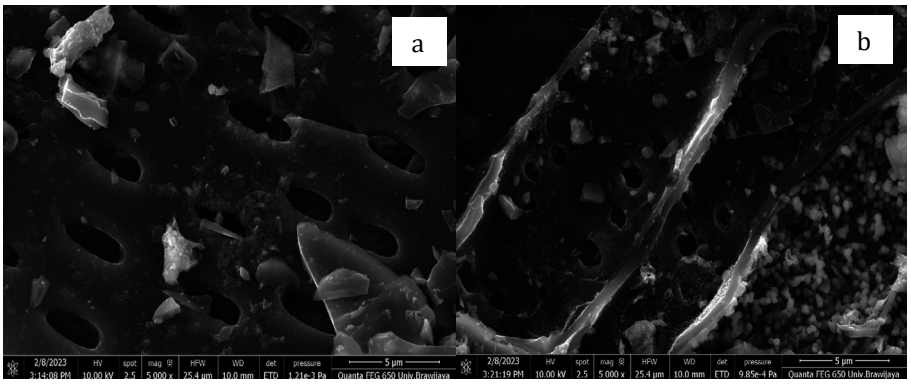

Fig. 3 *The scanning electron microscopy of bamboo charcoal (a) GA; (b) BV*

Because there are still impurities in the activated carbon pores before activation, which causes the pores to become closed and small, there are differences in the size of the pores before and after activation. These additional chemicals include hydrogen, tar, and other organic compounds made up of ash, water, nitrogen, and Sulphur. The HCl activator is added to bind impurities that would otherwise depart through the pores of the activated carbon, causing the surface to enlarge and increasing the absorption capacity of the active carbon. Numerous, bigger pores are created because of the activation process. These results show that activation consistently increases the number and size of pores in the two varieties of bamboo that were investigated. The increased quantity of open pores directly affects the surface area of CA. As a result, a larger surface area improves CA's ability to adsorb during the adsorption process. The activated carbon derived from BV has a pore size of 0.9155 µm prior to activation, which increases to 5.775 µm after activation. Upon adsorption, the adsorbates are shown to occupy the pores, effectively covering them. These observations were made at a magnification of 5,000X.

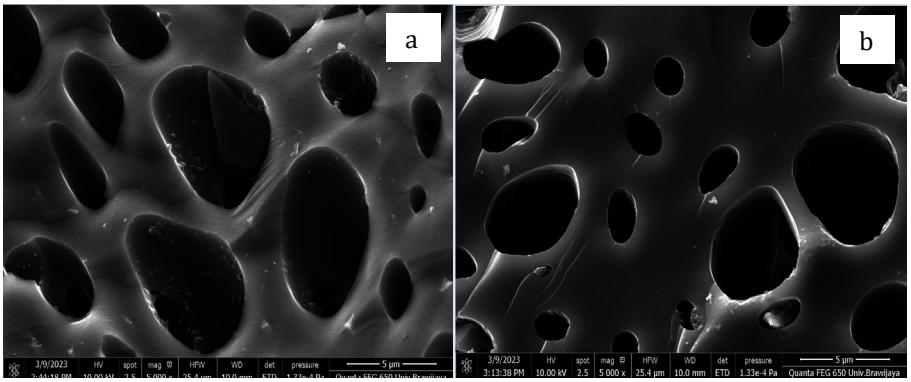

Fig. 4 *SEM of bamboo charcoal after activation with HCl (a) GA; (b) BV*

Prior to activation, the pore size of activated carbon from GA is 1.224 μm; after activation, the pore size is 4.495 μm; and following adsorption, it appears that there are adsorbates in the pores that are covering the pores. So, according to the image, there is a difference in pore size before and after activation, and the surface of the activated carbon has changed following adsorption. Dehydrating agents might also include HCl. The charcoal will react with HCl during the activation process, which will dissolve it and cause pores to form. The development of these holes would increase the activated charcoal's surface area, which will impact how well it absorbs substances. Removing contaminants and expanding pore volume are the two goals of the activation process. This is expanding the diameter of already-existing pores and forming new ones. Volatile materials and contaminants are eliminated from the sample because of the oxidation of the carbon content during activation. The volume and quantity of holes increase because of this oxidation process, increasing the surface area.

How much and what kind of activator is used has a significant impact on the chemical activation process. Higher activator concentrations increase the permeability of the carbon structure, allowing for the expansion of pores, the elimination of impurities, and the formation of new ones. The Van der Waals force—a weak attractive force between the adsorbate and the adsorbent surface—causes situations in activated carbon where it is apparent that there are adsorbates connected to the surface of the active carbon pores after adsorption. Additionally, agitation treatment improves the contact between the absorbent and adsorbate, which raises the likelihood of stronger Van der Waals forces. Energy dispersive spectroscopy (EDS) analysis was used to assess the element composition of the activated carbons in GA and BV before and after adsorption, as shown in Table 3. The presence of P, Na, S, and Mg, four new elements, in BV and GA may be seen. Element growth and decrease can be found in both BV and GA. As opposed to C, which decreases, the elements that rise are O, K, Cl, and Si. Activated carbon's ability to add and remove elements suggests that BV has a greater capacity for absorption than GA based on the results of the EDS test.

The quantities of cellulose and lignin present in each variety of bamboo employed also has an impact on BV's superior capacity to digest liquid waste compared to GA. GA has 24.6% lignin and 52.1% cellulose, compared to 25.6% lignin and 45.3% cellulose in BV. Because of this, GA produces more carbon than BV does as a result. The amount of lignin and cellulose in the raw materials that are carbonized to create charcoal affects the carbon content [34]. Due to its higher carbon content than cellulose and hemicellulose, lignin plays a more significant role in this situation than cellulose does. Due to its higher carbon concentration, activated carbon from BV may handle medical liquid waste more effectively than that from GA.

4. Conclusions

The study explores the adsorption of activated bamboo charcoal in liquid medical waste. FTIR spectra reveal an increase in absorption intensity, particularly within the hydroxyl group, indicating the synthesis of aromatic chemicals. The activation process does not eliminate the functional groups of activated carbon, which act as active sites for the adsorption process. Variations in pH levels can be attributed to drying duration, which affects surface quality and pore count. A longer agitation time leads to greater absorption of ions from the waste, increasing the pH level inside the waste. The TDS value decreases with increased agitation time with both BV and GA activated carbon. BV activated carbon exhibits a higher carbon content compared to GA activated carbon, leading to a reduction in TDS concentration in treated wastewater. SEM-based morphological examination shows that AC possesses a more porous morphology than BC. The activation process aims to remove contaminants and expand pore volume by expanding the diameter of existing pores and forming new ones. The Van der Waals force also plays a role in the adsorption process.

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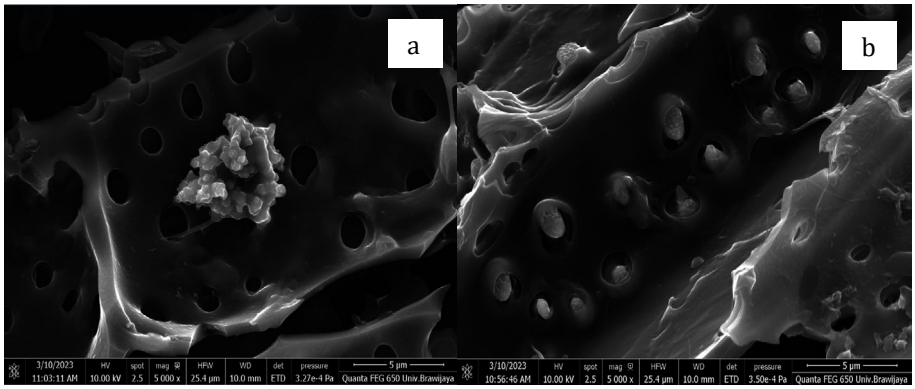

Fig. 5 *SEM image of CA after the medical waste adsorption process (a) GA; (b) BV*

Table 3 *Composition of BV and GA*

Element (%)	BV		GA	
	Before	After	Before	After
C	89,93	81.13	93.85	86.19
O	9.85	17.26	5.53	12.33
K	0.05	0.8	0.15	0.14
P	-	0.11	-	0.1
Na	-	0.29	-	0.05
S	-	0.19	-	0.24
Mg	-	0.09	-	0.07
Cl	0.07	0.08	0.27	0.05
Si	0.1	0.05	0.2	0.83

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Putu Hadi Setyarini, Felixanto Cendikia, Achmad As'ad Sonief;* ***data collection:*** *Felixanto Cendikia;* ***analysis and interpretation of results:*** *Putu Hadi Setyarini, Felixanto Cendikia;* ***draft manuscript preparation:*** *Putu Hadi Setyarini. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Kelkar, B., Shukla, S., Nagraik, P., & Paul, B. (2023, May). Structural bamboo composites: A review of processing, factors affecting properties and recent advances. *Advances in Bamboo Science*, *3*, 100026. https://doi.org/10.1016/j.bamboo.2023.100026

[2] Emamverdian, A., Ding, Y., Ranaei, F., & Ahmad, Z. (2020, September 30). Application of Bamboo Plants in Nine Aspects. *The Scientific World Journal*, *2020*, 1–9. https://doi.org/10.1155/2020/7284203

[3] Mondal, S., Jatrana, A., Maan, S., & Sharma, P. (2023, March 22). Lignin modification and valorization in medicine, cosmetics, environmental remediation and agriculture: a review. *Environmental Chemistry Letters*, *21*(4), 2171–2197. https://doi.org/10.1007/s10311-023-01585-3

[4] Bintarto, R., Widodo, T. D., Raharjo, R., Sulistyo, E., & Tamtomo, B. (2022, January 28). The Effect of Boiling Time of Wulung Bamboo Fiber (Gigantochloa Atroviolacea) in NaOH Solution on Tensile Strength of Epoxy Matriced Composites. *International Journal of Mechanical Engineering Technologies and Applications*, *3*(1), 15. https://doi.org/10.21776/mechta.2022.003.01.3

[5] Lamaming, J., Saalah, S., Rajin, M., Ismail, N. M., & Yaser, A. Z. (2022, February 2). A Review on Bamboo as an Adsorbent for Removal of Pollutants for Wastewater Treatment. *International Journal of Chemical Engineering*, *2022*, 1–14. https://doi.org/10.1155/2022/7218759

[6] Chen, Y. T., Huang, Y. P., Wang, C., Deng, J. G., & Hsi, H. C. (2020, June 2). Comprehending adsorption of methylethylketone and toluene and microwave regeneration effectiveness for beaded activated carbon derived from recycled waste bamboo tar. *Journal of the Air & Waste Management Association*, *70*(6), 616–628. https://doi.org/10.1080/10962247.2020.1742247
[7] Neme, I., Gonfa, G., & Masi, C. (2022, December). Activated carbon from biomass precursors using phosphoric acid: A review. *Heliyon*, *8*(12), e11940. https://doi.org/10.1016/j.heliyon.2022.e11940
[8] Lou, Z., Zheng, Z., Yan, N., Jiang, X., Zhang, X., Chen, S., Xu, R., Liu, C., & Xu, L. (2023, November 18). Modification and Application of Bamboo-Based Materials: A Review—Part II: Application of Bamboo-Based Materials. *Forests*, *14*(11), 2266. https://doi.org/10.3390/f14112266
[9] Mohd Zawawi, N., Hamzah, F., Veny, H., Mohd Rodhi, M. N., & Sarif, M. (2021, December 30). Chemical and Electrochemical Properties of Bamboo Activated Carbon Activate Using Potassium Hydroxide Assisted by Microwave-Ultrasonic Irradiation. *ASEAN Journal of Chemical Engineering*, *21*(2), 211. https://doi.org/10.22146/ajche.64617
[10] Chai, W. S., Cheun, J. Y., Kumar, P. S., Mubashir, M., Majeed, Z., Banat, F., Ho, S. H., & Show, P. L. (2021, May). A review on conventional and novel materials towards heavy metal adsorption in wastewater treatment application. *Journal of Cleaner Production*, *296*, 126589. https://doi.org/10.1016/j.jclepro.2021.126589
[11] Raza, A., Altaf, S., Ali, S., Ikram, M., & Li, G. (2022, July). Recent advances in carbonaceous sustainable nanomaterials for wastewater treatments. *Sustainable Materials and Technologies*, *32*, e00406. https://doi.org/10.1016/j.susmat.2022.e00406
[12] Shrestha, R., Ban, S., Devkota, S., Sharma, S., Joshi, R., Tiwari, A. P., Kim, H. Y., & Joshi, M. K. (2021, August). Technological trends in heavy metals removal from industrial wastewater: A review. *Journal of Environmental Chemical Engineering*, *9*(4), 105688. https://doi.org/10.1016/j.jece.2021.105688
[13] Baig, U., Faizan, M., & Sajid, M. (2021, June). Effective removal of hazardous pollutants from water and deactivation of water-borne pathogens using multifunctional synthetic adsorbent materials: A review. *Journal of Cleaner Production*, *302*, 126735. https://doi.org/10.1016/j.jclepro.2021.126735
[14] Nishat, A., Yusuf, M., Qadir, A., Ezaier, Y., Vambol, V., Ijaz Khan, M., Ben Moussa, S., Kamyab, H., Sehgal, S. S., Prakash, C., Yang, H. H., Ibrahim, H., & Eldin, S. M. (2023, August). Wastewater treatment: A short assessment on available techniques. *Alexandria Engineering Journal*, *76*, 505–516. https://doi.org/10.1016/j.aej.2023.06.054
[15] Kalderis, D., Seifi, A., Kieu Trang, T., Tsubota, T., Anastopoulos, I., Manariotis, I., Pashalidis, I., & Khataee, A. (2023, May). Bamboo-derived adsorbents for environmental remediation: A review of recent progress. *Environmental Research*, *224*, 115533. https://doi.org/10.1016/j.envres.2023.115533
[16] Harimisa, G., Jusoh, N., Tan, L., & Ghafar, N. (2023, October). Influence of furnace atmospheres and potassium hydroxide activation on the properties of bamboo activated carbon and its adsorption towards 4-nitrophenol. *Chemical Engineering Research and Design*, *198*, 325–339. https://doi.org/10.1016/j.cherd.2023.09.008
[17] Ji, Y., Zhang, C., Zhang, X., Xie, P., Wu, C., & Jiang, L. (2022, July). A high adsorption capacity bamboo biochar for CO2 capture for low temperature heat utilization. *Separation and Purification Technology*, *293*, 121131. https://doi.org/10.1016/j.seppur.2022.121131
[18] Suhaimi, N., Kooh, M. R. R., Lim, C. M., Chou Chao, C. T., Chou Chau, Y. F., Mahadi, A. H., Chiang, H. P., Haji Hassan, N. H., & Thotagamuge, R. (2022, February 14). The Use of Gigantochloa Bamboo-Derived Biochar for the Removal of Methylene Blue from Aqueous Solution. *Adsorption Science & Technology*, *2022*, 1–12. https://doi.org/10.1155/2022/8245797
[19] Rajesh, Y., Pilli, S. R., Ali, W., Motana, S., Khan, M. E., Bashiri, A. H., & Zakri, W. (2023, November). Synthesis of activated biochar from sustainable bamboo resources: An environment-friendly and low-cost solution for palladium (II) removal from wastewater. *Chemosphere*, *341*, 139944. https://doi.org/10.1016/j.chemosphere.2023.139944
[20] Geng, B., Xu, Z., Liang, P., Zhang, J., Christie, P., Liu, H., Wu, S., & Liu, X. (2021, November). Three-dimensional macroscopic aminosilylated nanocellulose aerogels as sustainable bio-adsorbents for the effective removal of heavy metal ions. *International Journal of Biological Macromolecules*, *190*, 170–177. https://doi.org/10.1016/j.ijbiomac.2021.08.186
[21] Nguyen, D., Vu, C., Vu, H., & Choi, H. (2019, April 30). Micron-Size White Bamboo Fibril-Based Silane Cellulose Aerogel: Fabrication and Oil Absorbent Characteristics. *Materials*, *12*(9), 1407. https://doi.org/10.3390/ma12091407
[22] Qu, J., Meng, Q., Peng, W., Shi, J., Dong, Z., Li, Z., Hu, Q., Zhang, G., Wang, L., Ma, S., & Zhang, Y. (2023, October). Application of functionalized biochar for adsorption of organic pollutants from environmental media: Synthesis strategies, removal mechanisms and outlook. *Journal of Cleaner Production*, *423*, 138690. https://doi.org/10.1016/j.jclepro.2023.138690

[23] Abegunde, S. M., Idowu, K. S., Adejuwon, O. M., & Adeyemi-Adejolu, T. (2020, September). A review on the influence of chemical modification on the performance of adsorbents. *Resources, Environment and Sustainability*, *1*, 100001. https://doi.org/10.1016/j.resenv.2020.100001
[24] Kim, S., Nam, S. N., Jang, A., Jang, M., Park, C. M., Son, A., Her, N., Heo, J., & Yoon, Y. (2022, January). Review of adsorption–membrane hybrid systems for water and wastewater treatment. *Chemosphere*, *286*, 131916. https://doi.org/10.1016/j.chemosphere.2021.131916
[25] Iwuozor, K. O., Ighalo, J. O., Emenike, E. C., Ogunfowora, L. A., & Igwegbe, C. (2021). Adsorption of Methyl Orange: An Empirical Study on Adsorbent Performance. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3903971
[26] Bichave, M. S., Kature, A. Y., Koranne, S. V., Shinde, R. S., Gongle, A. S., Choudhari, V. P., Topare, N. S., Raut-Jadhav, S., & Bokil, S. A. (2023). Nano-metal oxides-activated carbons for dyes removal: A review. *Materials Today: Proceedings*, *77*, 19–30. https://doi.org/10.1016/j.matpr.2022.08.451
[27] Azam, K., Shezad, N., Shafiq, I., Akhter, P., Akhtar, F., Jamil, F., Shafique, S., Park, Y. K., & Hussain, M. (2022, November). A review on activated carbon modifications for the treatment of wastewater containing anionic dyes. *Chemosphere*, *306*, 135566. https://doi.org/10.1016/j.chemosphere.2022.135566
[28] Manasa, P., Sambasivam, S., & Ran, F. (2022, October). Recent progress on biomass waste derived activated carbon electrode materials for supercapacitors applications—A review. *Journal of Energy Storage*, *54*, 105290. https://doi.org/10.1016/j.est.2022.105290
[29] Al-Ahmed, A., Mazumder, M. A. J., Salhi, B., Sari, A., Afzaal, M., & Al-Sulaiman, F. A. (2021, March). Effects of carbon-based fillers on thermal properties of fatty acids and their eutectics as phase change materials used for thermal energy storage: A Review. *Journal of Energy Storage*, *35*, 102329. https://doi.org/10.1016/j.est.2021.102329
[30] Oke, M. A., Sonibare, J. A., Onakpohor, A., Odunlami, O. A., Akeredolu, F. A., & Elehinafe, F. B. (2022, September). Proximate analysis of some common charcoal in Southwestern Nigeria. *Results in Engineering*, *15*, 100454. https://doi.org/10.1016/j.rineng.2022.100454
[31] Arang Aktif Teknis - SNI 06-3730-1995
[32] Budihardjo, M. A., Wibowo, Y. G., Ramadan, B. S., Serunting, M. A., Yohana, E., & Syafrudin. (2021, November). Mercury removal using modified activated carbon of peat soil and coal in simulated landfill leachate. *Environmental Technology & Innovation*, *24*, 102022. https://doi.org/10.1016/j.eti.2021.102022
[33] Chairunnisa, Mikšík, F., Miyazaki, T., Thu, K., Miyawaki, J., Nakabayashi, K., Wijayanta, A. T., & Rahmawati, F. (2020, December). Enhancing water adsorption capacity of acorn nutshell based activated carbon for adsorption thermal energy storage application. *Energy Reports*, *6*, 255–263. https://doi.org/10.1016/j.egyr.2020.11.038
[34] Massuque, J., De Assis, M. R., Loureiro, B. A., Matavel, C. E., & Trugilho, P. F. (2021, March 3). Influence of lignin on wood carbonization and charcoal properties of Miombo woodland native species. *European Journal of Wood and Wood Products*, *79*(3), 527–535. https://doi.org/10.1007/s00107-021-01669-3