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Research Article

Banana Stem Charcoal as Adsorbents Reduce Water Hardness Levels

Ronny[1], Irfa'i[2], Dedi Mahyudin[3], Jasman[4]

[1]Department of Environmental Health, Politeknik Kesehatan Kemenkes Makassar, Makassar 90222, Indonesia
[2]Department of Environmental Health, Politeknik Kesehatan Kemenkes Banjarmasin, Banjarmasin 70714, Indonesia
[3]Department of Environmental Health, Politeknik Kesehatan Kemenkes Palu, Palu 94145, Indonesia
[4]Department of Environmental Health, Politeknik Kesehatan Kemenkes Manado, Manado 95263, Indonesia
*Contact email: ronnymuntu@gmail.com, m_irfaimt@yahoo.co.id, dmahyuddin21@gmail.com, jasman@gmail.com.

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Abstract: One of the chemical parameters in the requirements of clean water is water hardness. Hardness is a term used in water containing cations that cause hardness. Generally, hardness caused by the presence of metals or cations which have a valence of 2, such as Fe, Sr, Mn, Ca and Mg. The purpose of this research is to determine the effect of banana stem charcoal as an adsorbent in reducing water hardness. The process of charcoal banana stem adsorbent dried under the sun for one week, and in the oven at 110°C for 24 hours to reduce moisture and moisture content. Next, to remove volatile materials, the hydrolyzed sample was heated at 400°C to become charcoal with 30 minutes in the furnace after which it was sieved with 106 μm and 250 μm sieves and stored in a desiccator. From the results of the study, it found that the banana charcoal adsorption process can reduce the water hardness level to reach 43.56% for the contact time of about 240 minutes with the thickness of the charcoal used around 5 cm. Then from the t-test analysis showed a significant difference before and after using banana stem charcoal as an adsorbent medium. Banana stem charcoal can be an alternative to adsorbent media to reduce the level of water pollution in addition to other media that commonly used.

Keywords: Adsorption Process, Activated Charcoal, Carbon-containing Materials, Pollution Water, Water Quality.

1. Introduction

Water needed by humans is not just any water but the water that is truly healthy and does not interfere with human health [1]. The importance of the role of water for human life, not only for life processes, but also for other processes such as industry, agriculture, and others.

Good water quality determined by several parameters including physical, chemical and biological parameters [2]. One of the biochemical parameters that define good water quality is the content of mineral salts. The content of mineral salts in groundwater varies from one region to another due to the different layers of soil in each area. For example, groundwater in calcareous soils have high Ca $(HCO3)_2$ and Mg $(HCO3)_2$ mineral salts. Due to the high content of mineral salts Ca $(HCO3)_2$ and Mg $(HCO3)_2$ which causes hardness of water. The hardness of water is used to show the salt content of calcium and magnesium dissolved in water expressed in (mg/L) calcium carbonate [3]. According to [4], hard water will have a health impact such as heart blood clots (cardiovascular disease) and kidney stone disease (urolithiasis), where consuming high levels of hardness can cause kidney failure, and cause movement in the equipment cooking and waste in the use of soap due to the froth produced little. In the Regulation of the Minister of Health of the Republic of Indonesia Number 32 the Year 2017 regarding the requirements for quality of clean water, it implies that the maximum level for hardness in water is 500 mg/L.

Provision of clean water, in addition to its quantity, the quality must meet applicable standards. In the case of fresh water, it is common practice that in determining the quality and characteristics associated with certain water

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quality standards (water quality standards) [5]. To obtain a clear picture of the characteristics of raw water, it is often necessary to measure the properties of water or commonly called water quality parameters, which are diverse [6].

Total hardness is hardness caused by Ca and Mg ions related to Cl_2SO_4 and NO_3, for example, $CaCl_2$ and $MgSO_4$. The nature of hardness cannot remove by boiling water but the softening process through the process of lime, soda ash, zeolite process, and absorption process [7]. Total resistance mainly caused by calcium and magnesium secondary to carbonate and bicarbonate (carbonate or temporary hardness which can be removed by heating) and calcium sulfate, calcium chloride, magnesium sulfate and magnesium chloride (noncarbonate or permanent hardness, which cannot be released by heat) [7], [8]. Total hardness expressed as calcium carbonate.

One method for treating water is through the adsorption process. The adsorption process can be carried out with activated carbon made from carbon-containing waste fuel. The adsorption process is one of the waste treatment techniques which is expected to be used to reduce excessive metal concentration. An alternative application of the adsorption method with activated carbon chosen because of the large surface of activated carbon, high adsorption ability, easy application, and relatively low cost. Adsorbents that have been used in adsorption research by utilizing agricultural waste include adsorbents from coconut shell [9], [10]. Several activated carbons from biomass can be used as an adsorbent namely bagasse [11], [12], cocoa skin [13]–[15], and banana stems [16], [17].

The banana stem has the potential to be used as an adsorbent because many banana stems contain carbon or carbonic hydrate. The research conducted by [18], for the first time using electro-chemical nitrite sensor application, obtained HAC surface area of about 1465 m^2g^{-1} then from its contents there was about 61.12% carbon, hydrogen around 2,567%, nitrogen around 0.4315 and Sulphur around 0.349 %. The structure of activated carbon contains polar functional groups namely carboxyl, hydroxyl and carbonyl groups which can interact with compounds or ions in gas or liquid media [19], [20].

Indonesia is one of the largest producing countries of banana plants in the world. Tropical climate conditions and fertile soil support this. Banana plants are natural materials that are cheap, easy to obtain and can be renewed. The part of the banana plant that is widely used by the community is banana and banana leaves. The city rarely uses other parts of banana plants such as banana stems. A small portion of the population only uses banana stems as animal feed, while in large quantities it becomes garbage.

So far, research on activated carbon from banana stems is still limited to proving the possibility of banana stems used as raw material for making activated carbon as well as determining effective process conditions to make banana stem activated carbon that meets international quality standards. There are still not many studies that examine the use of activated carbon in banana stems from being applied to industrial or environmental problems.

Activated carbon is a very good and widely used adsorbent because the surface area and micropore volume are huge [21], the adsorption capacity is substantial, the adsorption kinetics rate is very fast and relatively easy to regenerate [22]. Activated carbon is one of the most popular adsorbents for removing metal ions from solution [23], [24]. Because the price is rather high commercially, the activated carbon is somewhat limited by developing countries. Therefore, activated carbon needs to produce from cheap local agricultural raw materials [25].

Activated carbon can be produced from various carbon-containing materials. Interest in the selection of raw materials (precursors) for large quantities of activated carbon is due to availability, affordable prices, and does not cause pollution, besides the process of making and using products is also considered [19].

Realizing the potential of banana stem charcoal as an adsorbent, it is necessary to develop further research on the utilization of banana stem charcoal as an adsorbent in reducing water hardness.

2. Research Methods

2.1. Materials

The banana stem (*Musa acuminate*) used in the study obtained from the environment around the study area, which is around Makassar City. The banana stems used obtained in the yard, the edges of another cropland and the river bank. The technique of taking water samples was carried out using a 1.5 Liter polyethylene bottle. The bottle is then immersed through the water surface when the bottle filled, then lifted tightly closed and then stored in an ice flask. The sample obtained was then measured for total hardness by complexometric titration.

2.2. Procedure

Processing is done to reduce hardness in the water by using banana stem charcoal media and processing that done chemically. Before processing banana stems that will be used as a medium in decreasing hardness, it has been activated first and then examined with high contact variations. After the inspection has done by chemical means, we will find out whether the charcoal media with influential contact duration decreases hardness or not. Activated charcoal can be made through two stages, namely carbonization (casting) and activation. Carbonation is a process of indoor casting without the presence of oxygen and other chemicals [26].

Preparation of charcoal banana stem adsorbent is cut into small pieces and dried in the sun for one week, and then heated at 110°C for 24 hours to reduce the moisture content and moisture of the sample. Next, to remove volatile materials, the sample is hydrolyzed by heating at 400°C to become charcoal with a time of 0.5 hours in the furnace. The furnace cooled for 1 hour to room temperature; then charcoal is removed from the furnace and then crushed with mortar after it sifted with a sieve of 106µm and 250 µm and stored in a desiccator. This adsorption method has advantages over other methods because the process is more straightforward, the costs are relatively cheap, environmentally friendly [27], [28], and there are no side effects of toxic substances [29].

The variation of contact time for banana stem charcoal as an adsorbent range from 30, 60, 90, 120, 150, 180, 210, 240 minutes with the thickness of the banana stem charcoal at the test site about 5 cm.

2.3. Data Analysis

TDS meter (Water Hardness Tester) is used to measure the level of hardness of water. This meter applies the electrode method to test and has the same accuracy as the EDTA titration method with mg/L unit output. From the output, the analysis was then carried out to see a decrease in water hardness from before to after using banana stem charcoal as a filter medium. IBM SPSS is used to determine the level of difference in measurement results from before to after using banana stem charcoal.

3. Results and Discussions

Adsorption is a physical or chemical event on the surface that is influenced by a chemical reaction between the adsorbent and the adsorbate. Adsorbents are solids which can adsorb while adsorbates are solids, liquids, or adsorbed gases. Thus, the adsorption process can occur between solids and solids, gases with solids, gases with liquids, liquids with fluids, and liquids with solids [30]–[32]

Table 1. Adsorption of Banana Stem Carbon at Variations in Time of Contact With a thickness of 5 cm.

Contact Time (minutes)	Total hardness (mg/L)		Decreased Levels (mg/L)
	Before	After	
30	396.2	255.3	140.9
60	396.2	249.5	146.7
90	396.2	242.1	154.1
120	396.2	233.4	162.8
150	396.2	229.7	166.5
180	396.2	225.8	170.4
210	396.2	224.1	172.1
240	396.2	223.6	172.6

The process of banana charcoal adsorption using a time variation of 240 minutes with a thickness of 5 cm on average decreased 160.8 mg/L. This study uses variations in contact time with the same media thickness. The longer the contact time of the water sample and the charcoal of the banana stem, the higher the level of decrease in total hardness. Because the longer the contact time of the water sample and banana charcoal, the higher the ability of the media to reduce hardness, because of the attractive strength of absorbent molecules, the adsorption process occurs from the material used, the banana charcoal produces soft and suitable charcoal to purify the water. Namely the process of absorption of substances that will be removed by the surface of the active charcoal of banana stems, including $CaCO_3$ which causes hardness.

The amount of adsorption ability of activated carbon produced does not depend on the specific surface area determined according to Brunauer-Emmett-Teller (BET) [33]. The quality of the active charcoal surface produced is very dependent on the raw material, activating material, temperature, and method of activation [34]–[36].

Adsorption is the process of collecting soluble substances that are present in the solution by the surface of an absorbent object where there is a physical-chemical bond between the substance and its absorbent [37]. In general, liquid adsorption with carbon adsorbent used for color bleaching, water purification, solution. Bhattacharyya and Gupta [38], states that the adsorption of liquid with carbon adsorbent is used to remove odor, taste, and color in the water. More specific applications in the industry include bleaching of colors in sugar factory wastes, elimination of contaminants for sulfur, phenol, and hydrocarbons from liquid waste.

Activated charcoal which is an adsorbent, is a porous solid which consists mainly of free carbon elements and each of them bonded covalently [39]. Thus, the surface of activated charcoal is non-polar. In addition to composition and polarity, the pore structure is also an essential factor to consider [40]. The pore structure is related to the surface area, the smaller the active pores of charcoal, the higher the surface area [41]. Thus, the adsorption speed increases. To increase the adsorption speed, it is recommended to use mashed activated charcoal. The most critical active charcoal properties are absorption.

The time of contact with banana stem charcoal in the study also affected the percentage decrease in hardness level. These results can be seen in Figure 1 below.

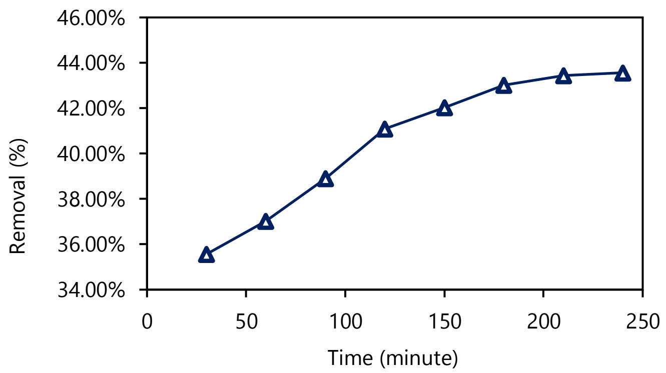

Figure 1. Decrease in Total Hardness Level with Banana Stem Charcoal as an Adsorbent.

Figure 1 shows that there is an increase in the percentage decrease in the length of time that banana stem char contact takes place. From the 30 minutes of contact time, a decrease of 35.56% to 240 minutes of contact time obtained at 43.56%. If averaged at every 30 minutes the contact time will decrease by around 1.14%. The process of adsorption of banana stem charcoal in this study was able to reduce the total hardness level by using a variation of about 30 minutes and a thickness of 5 cm with an average percentage reduction of about 40.58% and an average decrease of around 160.8 mg/L.

The ability of banana stem charcoal to reduce total hardness is caused by having a chemical composition in the form of cellulose. Cellulose is an organic compound [42], [43]. According to [44], banana stems contain cellulose around 60-65%. Cellulose has considerable potential to be used as an absorber because the OH group that is bound to cellulose when heated at high temperatures will lose hydrogen and oxygen atoms so that the carbon atom is located at each angle [45]. Another study conducted by [46], using head fiber, was obtained that the material is very potent as an adsorbent because it also contains cellulose which in its molecular structure contains phenolic acid which takes part in the binding of compounds such as metals. The ability of banana stem charcoal to absorb chemically is suspended into sample water so that the suspended banana stem charcoal affects the binding of Mg and Ca ions. The chemical reaction process is as follows:

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$$

With the formation of $CaCO_3$ deposits, it means that the water has been free of Ca_2 + and Mg_2 + ions or in other words the water has been free from hardness. So, it can be said that the adsorption with banana stem charcoal media can absorb substances dissolved in water because banana stem charcoal has pores that are adsorbent, meaning that they can absorb some smaller molecules shown from the results of laboratory tests after treatment.

Increased porosity also caused by the amount of impregnating agent used; the more activators used will increase the formation of pores on activated carbon [47]. Then according to [48], that with increasing surface area of the pores of activated carbon, the absorption of the dissolved substances will be higher.

Generally activated carbon is in the form of granular (granules) and powder. Fine powder-shaped activated carbon has a particle size distribution of 5-10 µm. While granular shaped activated carbon has a size of 0.8-1.2 mm. The porosity of activated carbon formed during the carbonization process. On activated carbon, there are three pore sizes, namely micropore (<2 nm), mesopore (2 nm - 50 nm), and macropore (>50 nm) (Marsh, 2006). In addition, there are also supermicropore (0.7 nm - 2 nm) and ultra-micropore (<0.7 nm) sizes [49]. The adsorption process only occurs on the surface, not in the bulk phase. The adsorption process mainly occurs in micropores (small pores), whereas the adsorbate transfer from the outer surface to the surface of the micropore is macropore.

Commercial activated carbon applications can be used as deodorizers and resins, a distillation of raw materials, purification of wastewater, water purifiers, and can be used as adsorbents to adsorb materials derived from liquids or gas phases [50]. The absorption of activated carbon itself is determined by the particle surface area, and this ability can be higher if activated carbon is activated by chemical activators or by heating at high temperatures [51].

Table 2 shows the results of the T-Test statistics to determine the level of the difference obtained before and after using banana stem charcoal as an absorbent material in water.

Hypothesis:

- H_0: There is a difference between before and after treatment.
- H_1: There is no difference between before and after treatment.

Basic Decision Making:

- If the value is Sig. or Probability Value <0.05, then H_0 is accepted.
- If the value is Sig. or Probability Value >0.05, then H_0 is rejected.

Table 2. Paired Samples Test Use of Banana Stem Charcoal.

	Mean	t	Sig. (2-tailed)
Before - After	160.763	37.390	0.000

From these results indicate that the value of sig. obtained <0.05 from before and after using banana stem charcoal as an absorbent medium in reducing water hardness. There is a significant difference which means that the treatment carried out is beneficial in reducing hardness levels in sample water.

This research conducted as an effort to reduce water hardness so that it can improve the quality of clean water for the community so that it no longer causes health problems caused by consuming water containing hardness that exceeds the allowable threshold value. Through this research, it is expected to be an alternative in treating water containing hardness levels as well as being an alternative for solving problems faced generally for people whose water sources include hardness. Therefore, these efforts need to be accompanied by the implementation of proven forms of processing to provide optimal and sustainable results; it hoped that this form of processing could be applied in the community.

4. Conclusions

The activated carbon charcoal from the banana stems was able to reduce the water hardness level significantly. By using simple equipment that can easily make and produced, it hoped that it could be applied to environments that have high levels of hardness in clean water. There is still a lot of agricultural waste that can become activated carbon which is useful in reducing pollution levels. Other studies still need to be carried out to obtain the best materials and processes for activated carbon. Making activated carbon is expected to produce a high surface area and can then be used in general.

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References

[1] Ronny, G. D. Dirawan, and M. Basir, "Strategies of Sanitation Environmental Counseling Towards Increasing Attitude of Community on Preserve Environment in Makassar City," *Int. J. Appl. Environ. Sci.*, vol. 11, no. 3, pp. 741–749, 2016.

[2] Ronny. and A. H. Hasim, "Effectiveness of Multiple Tray-Aerators in Reducing Iron (Fe) Water Wells in Gowa Regency, Indonesia," *Ecol. Environ. Conserv.*, vol. 24, no. 1, pp. 22–25, 2018.

[3] S. M. Khopkar, *Basic concepts of analytical chemistry*. New Age International, 1998.

[4] World Health Organization, "UN-Water Global Assessment of Sanitation and Drinking Water: Targeting resources for better results," World Health Organization (WHO), 2010.

[5] Ronny, G. D. Dirawan, M. Ardi, and B. Rauf, "Strategies for increasing Awareness on Environmental Sanitation in Maintenance Knowledge Society Environment in Makassar," *Man India*, vol. 96, no. 5, pp. 795–803, 2015.

[6] A. Hounslow, *Water quality data: analysis and interpretation*. CRC press, 2018.

[7] D. Garg, R. Kaur, D. Chand, S. K. Mehla, and R. V Singh, "Analysis of water quality of Bharatpur area in post-monsoon season, January 2007," *Rasayan J. Chem.*, vol. 1, no. 4, pp. 743–750, 2008.

[8] K. Rafferty, *Scaling in geothermal heat pump systems*. Geo-Heat Center Klamath Falls, OR, 1999.

[9] E. Bernard, A. Jimoh, and J. O. Odigure, "Heavy metals removal from industrial wastewater by activated carbon prepared from coconut shell," *Res. J. Chem. Sci.*, vol. 2231, 2013.

[10] O. S. Amuda, Aa. Giwa, and I. A. Bello, "Removal of heavy metal from industrial wastewater using modified activated coconut shell carbon," *Biochem. Eng. J.*, vol. 36, no. 2, pp. 174–181, 2007.

[11] V. C. Srivastava, M. M. Swamy, I. D. Mall, B. Prasad, and I. M. Mishra, "Adsorptive removal of phenol by bagasse fly ash and activated carbon: equilibrium, kinetics and thermodynamics," *Colloids surfaces a Physicochem. Eng. Asp.*, vol. 272, no. 1–2, pp. 89–104, 2006.

[12] V. K. Gupta and S. Sharma, "Removal of zinc from aqueous solutions using bagasse fly ash− a low cost adsorbent," *Ind. Eng. Chem. Res.*, vol. 42, no. 25, pp. 6619–6624, 2003.

[13] N. Meunier, J. Laroulandie, J. F. Blais, and R. D. Tyagi, "Cocoa shells for heavy metal removal from acidic solutions," *Bioresour. Technol.*, vol. 90, no. 3, pp. 255–263, 2003.

[14] C. Saucier *et al.*, "Microwave-assisted activated carbon from cocoa shell as adsorbent for removal of sodium diclofenac and nimesulide from aqueous effluents," *J. Hazard. Mater.*, vol. 289, pp. 18–27, 2015.

[15] M. C. Ribas *et al.*, "Comparison of a homemade cocoa shell activated carbon with commercial activated carbon for the removal of reactive violet 5 dye from aqueous solutions," *Chem. Eng. J.*, vol. 248, pp. 315–326, 2014.

[16] T. S. Anirudhan, P. Senan, and M. R. Unnithan, "Sorptive potential of a cationic exchange resin of carboxyl banana stem for mercury (II) from aqueous solutions," *Sep. Purif. Technol.*, vol. 52, no. 3, pp. 512–519, 2007.

[17] Z. Ab Ghani, M. S. Yusoff, N. Q. Zaman, M. F. M. A. Zamri, and J. Andas, "Optimization of preparation conditions for activated carbon from banana pseudo-stem using response surface methodology on removal of color and COD from landfill leachate," *Waste Manag.*, vol. 62, pp. 177–187, 2017.

[18] R. Madhu, V. Veeramani, and S. Chen, "Heteroatom-enriched and renewable banana-stem-derived porous carbon for the electrochemical determination of nitrite in various water samples," *Sci. Rep.*, vol. 4, no. 4679, 2014.

[19] H. Marsh and F. R. Reinoso, *Activated carbon*. Elsevier, 2006.

[20] A. Dąbrowski, P. Podkościelny, Z. Hubicki, and M. Barczak, "Adsorption of phenolic compounds by activated carbon—a critical review," *Chemosphere*, vol. 58, no. 8, pp. 1049–1070, 2005.

[21] I. H. Aljundi and N. Jarrah, "A study of characteristics of activated carbon produced from Jordanian olive cake," *J. Anal. Appl. Pyrolysis*, vol. 81, no. 1, pp. 33–36, 2008.

[22] D. Mohan, K. P. Singh, and V. K. Singh, "Wastewater treatment using low cost activated carbons derived from agricultural byproducts—a case study," *J. Hazard. Mater.*, vol. 152, no. 3, pp. 1045–1053, 2008.

[23] A. Kassim, C. G. J. A. Joseph, Z. Zainal, M. Z. Hussein, M. J. Haron, and A. H. Abdullah, "Activated carbons prepared from oil palm shells: application for column separation of heavy metals," *J. Indian Chem. Soc.*, vol. 81, no. 11, pp. 946–949, 2004.

[24] Y. Kikuchi, Q. Qian, M. Machida, and H. Tatsumoto, "Effect of ZnO loading to activated carbon on Pb (II) adsorption from aqueous solution," *Carbon N. Y.*, vol. 44, no. 2, pp. 195–202, 2006.

[25] S. J. T. Pollard, G. D. Fowler, C. J. Sollars, and R. Perry, "Low-cost adsorbents for waste and wastewater treatment: a review," *Sci. Total Environ.*, vol. 116, no. 1–2, pp. 31–52, 1992.

[26] H. Jankowska, A. Świątkowski, and J. Choma, *Active carbon*. Ellis Horwood Ltd, 1991.

[27] T. Patel-Weynand, "Biodiversity and sustainable forestry: State of the science review," *Rep. Natl. Comm. Sci. Sustain. For. Washington, DC*, 2002.

[28] K. G. Bhattacharyya and S. Sen Gupta, "Kaolinite and montmorillonite as adsorbents for Fe (III), Co (II) and Ni (II) in aqueous medium," *Appl. Clay Sci.*, vol. 41, no. 1–2, pp. 1–9, 2008.

[29] P. Drogui, R. Daghrir, M.-C. Simard, C. Sauvageau, and J. F. Blais, "Removal of microcystin-LR from spiked water using

either activated carbon or anthracite as filter material," *Environ. Technol.*, vol. 33, no. 4, pp. 381–391, 2012.

[30] A. W. Adamson and A. P. Gast, *Physical chemistry of surfaces*, vol. 150. Interscience New York, 1967.

[31] W. J. Weber and J. C. Morris, "Kinetics of adsorption on carbon from solution," *J. Sanit. Eng. Div.*, vol. 89, no. 2, pp. 31–60, 1963.

[32] D. M. Ruthven, *Principles of adsorption and adsorption processes*. John Wiley & Sons, 1984.

[33] G. G. Stavropoulos, P. Samaras, and G. P. Sakellaropoulos, "Effect of activated carbons modification on porosity, surface structure and phenol adsorption," *J. Hazard. Mater.*, vol. 151, no. 2–3, pp. 414–421, 2008.

[34] M. E. Fernandez, G. V. Nunell, P. R. Bonelli, and A. L. Cukierman, "Activated carbon developed from orange peels: Batch and dynamic competitive adsorption of basic dyes," *Ind. Crops Prod.*, vol. 62, pp. 437–445, 2014.

[35] R. R. Bansode, J. N. Losso, W. E. Marshall, R. M. Rao, and R. J. Portier, "Adsorption of metal ions by pecan shell-based granular activated carbons," *Bioresour. Technol.*, vol. 89, no. 2, pp. 115–119, 2003.

[36] S. Ismadji, Y. Sudaryanto, S. B. Hartono, L. E. K. Setiawan, and A. Ayucitra, "Activated carbon from char obtained from vacuum pyrolysis of teak sawdust: pore structure development and characterization," *Bioresour. Technol.*, vol. 96, no. 12, pp. 1364–1369, 2005.

[37] T. D. Reynolds and P. A. Richards, *Unit operations and processes in environmental engineering*, vol. 20. PWS Publishing Company Boston, MA, 1996.

[38] W. W. Eckenfelder, "Granular carbon adsorption of toxics," *Toxic. Reduct. Ind. Effluents. Van Nostrand Reinhold, New York. 1990. p 203-228, 12 fig, 4 tab, 5 ref.*, 1990.

[39] J. Lahaye, "The chemistry of carbon surfaces," *Fuel*, vol. 77, no. 6, pp. 543–547, 1998.

[40] H. Marsh, "Adsorption methods to study microporosity in coals and carbons—a critique," *Carbon N. Y.*, vol. 25, no. 1, pp. 49–58, 1987.

[41] E. C. Dillon Jr, J. H. Wilton, J. C. Barlow, and W. A. Watson, "Large surface area activated charcoal and the inhibition of aspirin absorption," *Ann. Emerg. Med.*, vol. 18, no. 5, pp. 547–552, 1989.

[42] N. Cordeiro, M. N. Belgacem, I. C. Torres, and J. Moura, "Chemical composition and pulping of banana pseudo-stems," *Ind. Crops Prod.*, vol. 19, no. 2, pp. 147–154, 2004.

[43] M. P. Adinugraha and D. W. Marseno, "Synthesis and characterization of sodium carboxymethylcellulose from cavendish banana pseudo stem (Musa Cavendishii Lambart)," *Carbohydr. Polym.*, vol. 62, no. 2, pp. 164–169, 2005.

[44] T. N. Gupta, "Building materials in India: 50 years," *Build. Mater. Technol. Promot. Counc. (New Delhi Minist. Urban Aff. Employment, Gov. India)*, 1998.

[45] J. S. Roden, G. Lin, and J. R. Ehleringer, "A mechanistic model for interpretation of hydrogen and oxygen isotope ratios in tree-ring cellulose," *Geochim. Cosmochim. Acta*, vol. 64, no. 1, pp. 21–35, 2000.

[46] G. H. Pino, L. M. S. de Mesquita, M. L. Torem, and G. A. S. Pinto, "Biosorption of heavy metals by powder of green coconut shell," *Sep. Sci. Technol.*, vol. 41, no. 14, pp. 3141–3153, 2006.

[47] L.-Y. Hsu and H. Teng, "Influence of different chemical reagents on the preparation of activated carbons from bituminous coal," *Fuel Process. Technol.*, vol. 64, no. 1–3, pp. 155–166, 2000.

[48] H. B. Allport, "Activated carbon," *McGraw-H ill Encycl. Sci.*, vol. 8, p. 94, 1977.

[49] S. M. Manocha, "Porous carbons," *Sadhana*, vol. 28, no. 1–2, pp. 335–348, 2003.

[50] S. Kvech and T. Erika, "Activated carbon," *United States Am. Dep. Civ. Environ. Eng. Virginia Tech Univ.*, 1998.

[51] E. Worch, *Adsorption technology in water treatment: fundamentals, processes, and modeling*. Walter de Gruyter, 2012.