Natural Sciences Engineering & Technology Journal (NASET Journal)

Journal Homepage: https://nasetjournal.com/index.php/nasetjournal

Experimental Study of Permeability Characteristics of Bamboo Betung Activated Carbon as Alternative Pad Material for Direct Evaporative Cooling System

I Made Feby Arya Putra[1*], Hendra Wijaksana[1], I Gede Teddy Prananda Surya[1]

[1]Mechanical Engineering Study Program, Faculty of Engineering, Universitas Udayana, Denpasar, Indonesia

ARTICLE INFO

Keywords:
Bamboo betung
Direct evaporative cooling
Pad material
Permeability

***Corresponding author:**
I Made Feby Arya Putra

E-mail address:
dekbiarya@gmail.com

All authors have reviewed and approved the final version of the manuscript.

https://doi.org/10.37275/nasetjournal.v3i1.27

A B S T R A C T

The increased growth in the building sector, especially in big cities, has triggered an increase in the need for electrical energy for cooling systems, most of which use compressor-based cooling systems. Direct Evaporative Cooling (DEC) is evaporative that produces cooling by utilizing the latent heat of evaporation of water on the wet surface of the pad material. The pad material must be sufficiently porous to allow the free flow of air through it and must have a large enough wet surface area. This study used carbonized and activated bamboo Betung as a material for the DEC system. The research was conducted to obtain the permeability characteristics of the carbonized bamboo pad material at various temperatures of 400°C, 500°C, 600°C, 700°C, and 800°C and then activated at a temperature of 600°C with a holding time of 60 minutes. Based on the results of the research on the permeability characteristics of bamboo Betung activated carbon material, which was carbonized at a temperature of 400°C and activated at a temperature of 600°C with a holding time of 60 minutes (ABR 400) had the highest permeability of 13.6 x 10^{-15} m^2. Meanwhile, the lowest permeability was produced by bamboo Betung material which was carbonized at a temperature of 800°C and activated at an activation temperature of 600°C with a holding time of 60 minutes (ABR 800) which is only 0.56x10^{-15} m^2.

1. Introduction

The increased growth in the building sector, especially in big cities, has triggered an increase in the need for electrical energy for cooling systems, most of which use compressor-based cooling systems. For this reason, many studies have been carried out to develop an alternative cooling system that is more environmentally friendly and energy-efficient. Direct Evaporative Cooling (DEC) is an evaporative cooling system that produces cooling by utilizing the latent heat of evaporation of water on the wet surface of the pad material. The main component of the DEC cooling system is the pad material, which is a cooling medium that is moistened with water for the evaporation process to take place. Many studies for the development of DEC system pad materials have been carried out, including research on DEC pad materials from pumice stone, volcanic tuff, and greenhouse shading net, and it was found that volcanic tuff produces a cooling performance close to that of commercial CELdek cellulose materials at an airflow velocity of 0.6 m/s. Another study stated that some local materials, such as coir fiber, produced a cooling efficiency of 89.6-92.8%, then fine fabric (47.22-85.51%), and coarse fabric (63.88-86.32%).[1-5] The pad material must be sufficiently porous to allow the free flow of air through it and must have a large enough wet surface area to produce saturated air. The study stated that Palash fiber had higher effectiveness of 26.31% and 13.2% than khus and aspen materials. It is also proven that Palash fiber has better water resistance capability from the material aspect.

However, this study was not clear and in detail, explained the porosity and water holding capacity of the material. Another study stated that the material in the evaporative cooling system must have good water absorption properties, be unreactive to the surrounding material, more rigid in moist (wet) conditions and the material pores are not too small so that it can cause a pressure drop.[6-11]

There has been no research using bamboo materials, especially carbonized and activated carbonized bamboo Betung, as a pad material for the DEC system, in an effort to develop a porous pad material that has more measurable porosity, permeability, and water holding capacity. The selection of local Balinese bamboo in this study was based on the fact that besides being quite abundant in Bali, it was also known that the physical characteristics of bamboo Betung had a reed wall thickness of 11-36 mm, a reed length of 40-50 cm and a reed diameter of 12-18(20) cm. With the thicker bamboo Betung reed walls, it will be possible to later be able to accommodate a larger amount of water mass or have large water retaining capacity. The higher the ability to hold water, it means that more heat will be absorbed by the air for evaporation, or it is said that its thermal capacity will increase. Activated bamboo charcoal has better absorptivity and absorptivity characteristics than wood-activated charcoal. Bamboo-activated charcoal has a much higher absorptivity than wood-activated charcoal because bamboo-activated charcoal has a specific surface area of around 150-400 m^2/g, which is almost 2-3 times larger than wood activated charcoal, so it can be used on a wider scale. For various purification and absorption applications, such as purification of drinking water, air filters, gas masks, mattresses, and pillows and/or for use in the purification industry.[12-16]

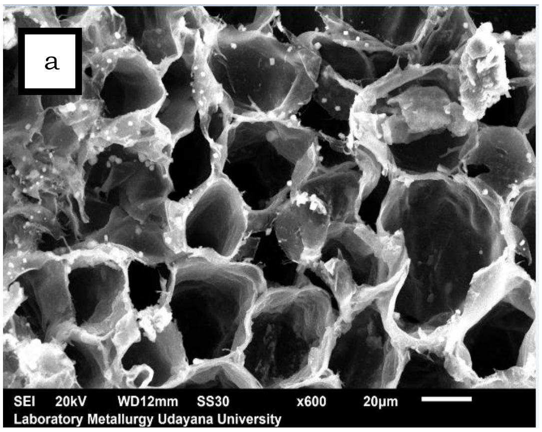
2. Methods

This study is an experimental study on the permeability characteristics of carbonized and carbon-activated bamboo Betung as an alternative pad material in the DEC system. In this study, bamboo Betung will be given carbonization treatment with variations in carbonization temperature of 400°C, 500°C, 600°C, 700°C, and 800°C. Then, each carbonized bamboo will be activated by carbon at an activation temperature of 600°C and carried out holding time for 60 minutes. By providing carbonization and carbon activation treatment with a holding time of 60 minutes on bamboo Betung, it is expected that there will be an increase in the microstructure of bamboo, which includes pore size, pore surface area, pore distribution, porosity, and also permeability. This increase in microstructure, porosity, and permeability is expected to be able to improve the water absorption and retention properties of the bamboo Betung, which will provide enough water for the bamboo material to ensure the ongoing evaporation process, which produces a cooling effect.

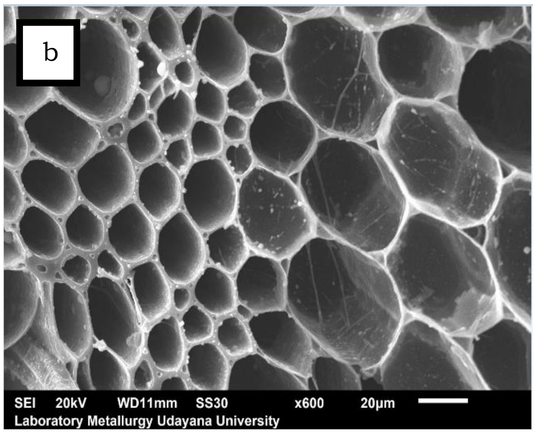
The bamboo Betung used as a test material or specimen in this study is a local Balinese bamboo Betung from the Baturiti area. This bamboo Betung is estimated to be 5-7 years old, with an outer circle of 34 cm and a reed thickness of 1.7 cm, where the outer skin thickness is 0.5 cm and the inner thickness is 1.2 cm. Carbonization process 400°C-800°C: (a) the first specimen is introduced into the carbonization reactor for the carbonization process of 400°C; (b) using a cup and aluminum foil to obtain oxygen-free conditions (inert atmosphere), then the temperature of the carbonization reactor was increased by the heating rate of 8.5°C/min and adjusted to 400°C; (c) then the specimen is cooled in a reactor for 12 hours and a specimen of bamboo charcoal Betung BR 400 will be produced. The next carbonization process is carried out by repeating steps a-c with carbonization temperatures of 500°C, 600°C, 700°C, and 800°C will produce bamboo charcoal specimens of BR 500, BR 600, BR 700, and BR 800. The next stage after the carbonization process is the activation process of carbon material with an activation temperature of 600°C with a holding time of 60 minutes: (a) the sample is heated first in an electric furnace at 40°C, then put into a heating reactor to carry out the carbon activation process at a temperature of 600^{o}C; (b) air is removed from the heating chamber by means of a vacuum pump; (c) N2 has flowed into the heating chamber at a flow rate of 50 mL/min; (d) the heating room temperature is increased to 600^{o}C at a rate of 8.5^{o}C/min from room temperature; (e) after the carbon activation temperature reaches 600^{o}C, then hold for 60 minutes on each sample of bamboo charcoal BR400, BR500, BR600, BR700, and BR800 will become activated bamboo charcoal. Bamboo charcoal samples from activation of 600^{o}C with a holding time of 30 minutes are codenamed as ABR 400 – ABR 800, where ABR 400 means that bamboo Betung activation material by heating 600^{o}C with a holding time of 60 minutes is carried out on a sample of BR 400 carbon material. For each end of the test, the heating reactor was cooled with a nitrogen flow of 10 mL/min until it reached room temperature, then the test material was removed from the heating reactor. The SEM (Scanning Electron Microscope) test is intended to obtain the pore structure characteristics of the ABR 400, ABR 500, ABR 600, ABR 700, and ABR 800 specimens. From the pore structure of the SEM test results and assisted by the application of Image J, can be determined the size of the pore, the distribution of pores, and the porosity of the material.

3. Results and Discussion

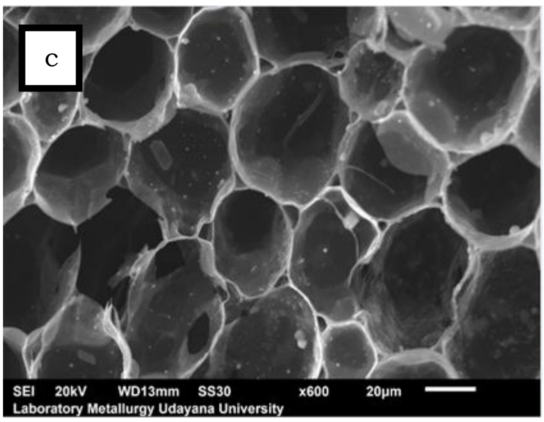
The following are the results of the Scanning Electron Microscope (SEM) test on bamboo Betung carbon material BR 400, BR 500, BR 600, BR 700, and BR 800, which can be seen in Figure 1(a – e) below.



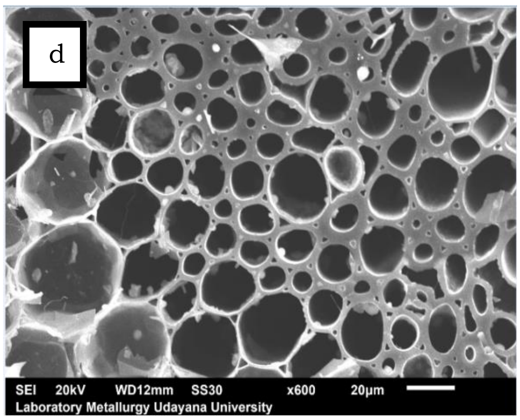
BR 400



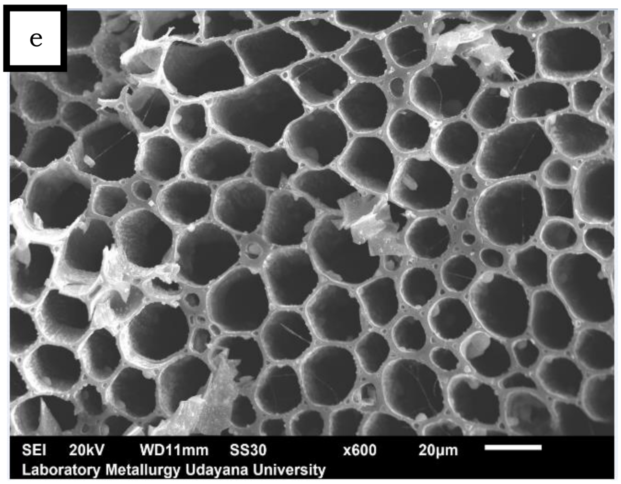
BR 500



BR 600



BR 700

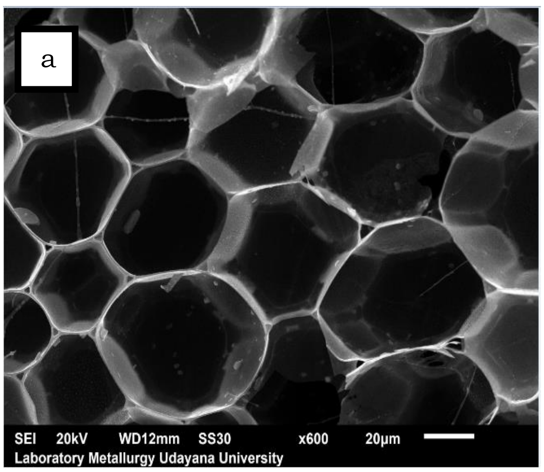


BR 800

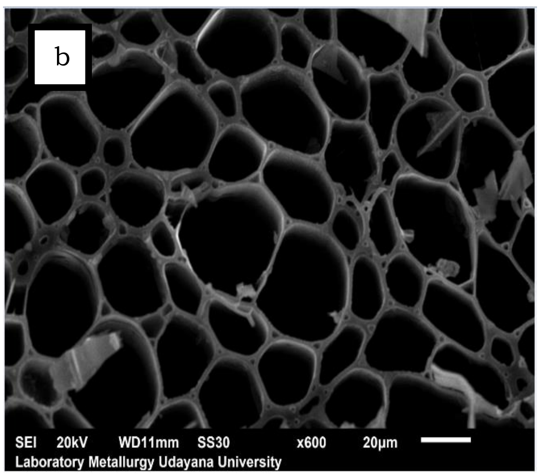
Figure 1. Microstructure of Betung bamboo carbon material (Before activation)

Figure 1. shows the pore microstructure of bamboo Betung carbon material (before activation). Figure 1 (a – e) respectively shows the bamboo Betung material that has undergone a carbonization process with a carbonization temperature of 400°C (BR 400), 500°C (BR 500), 600°C (BR 600), 700°C (BR 700) and 800°C (BR 800). In general, the carbonization process aims to open the initial pores of the bamboo Betung material. At this stage, there are still many bamboo pores that have not been opened because the heat of carbonization has not been accessed, which means that there are still a lot of solids contained in the bamboo stem that has not undergone the decomposition process so that it still closes the pores that should have been formed.

The results of the scanning electron microscope (SEM) test on activated carbon material (after activation) of bamboo Betung obtained the microporous structure of the material for ABR 400, ABR 500, ABR 600, ABR 700, and ABR 800 materials, respectively, as shown in Figure 2 (a – e).



ABR 400



ABR 500

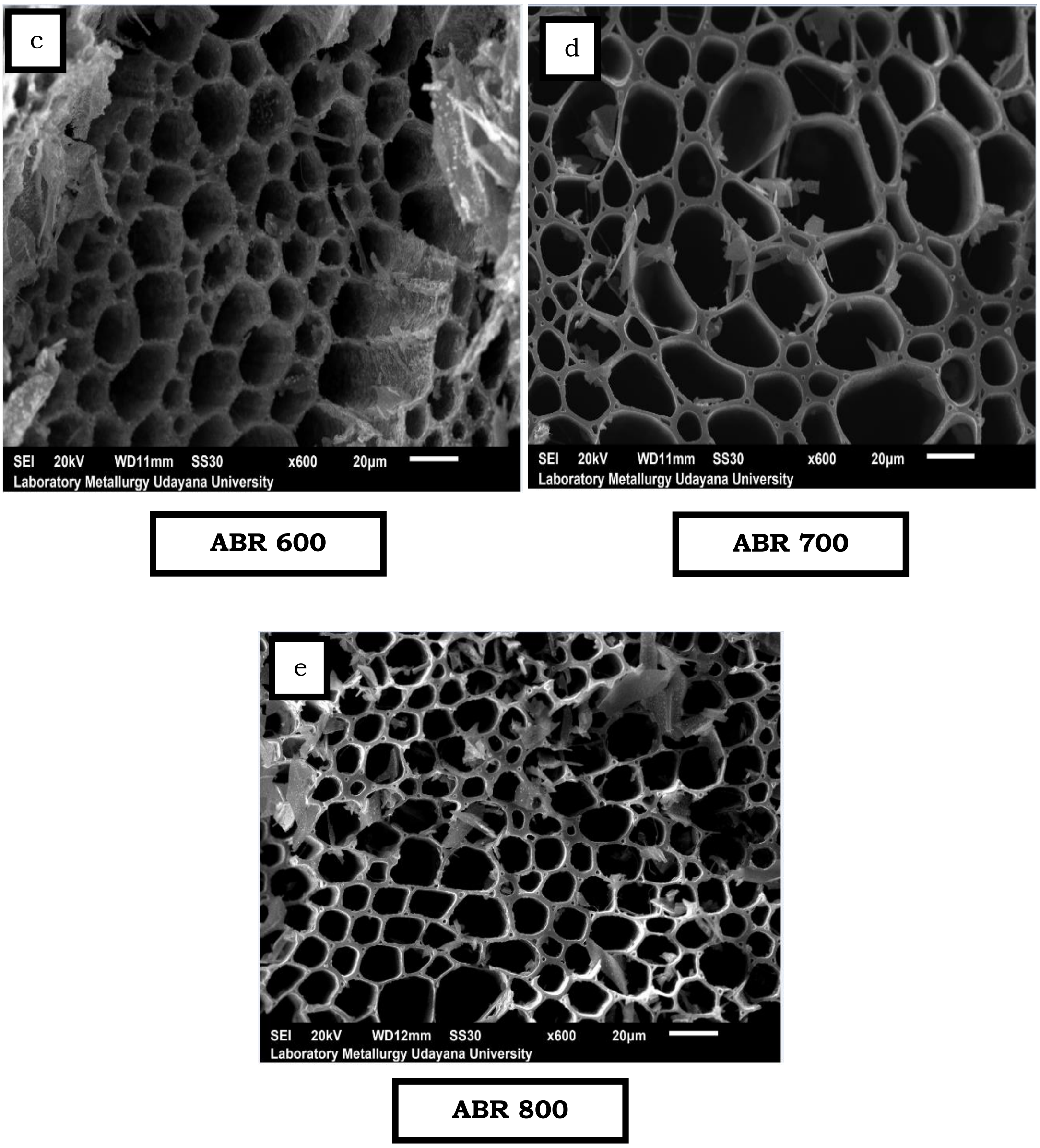


figure 2. micropore structure of Betung bamboo activated carbon material (After activation)

Based on the results of the scanning electron microscope (SEM) test on the bamboo betung activated carbon material, as shown in Figure 2, respectively, the microporous structure of each material obtained for the bamboo betung activated carbon material (a) ABR 400, (b) ABR 500, (c) ABR 600, (d) ABR 700 and (e) ABR 800. It can be seen in Figure 2 that the microporous structure formed on the bamboo betung activated carbon material above. In general, it can be seen that there is more small pore formation than before the process. Activation. each material is ABR 400, ABR 500, ABR 600, ABR 700 and ABR 800. The pore sizes formed are very diverse, so this bamboo betung activated carbon material can be categorized as producing heterogeneous pores. This is probably due to the difference in heat penetration received by each parenchyma cell which then turns into a pore material. In addition, this difference in pore size may also be caused by differences in the thinning of the bamboo cell walls due to the heat difference it receives, resulting in different pore wall thicknesses. It is stated in the literature that the higher the heating temperature (carbonization and carbon activation) will result in the formation of a porous carbonaceous structure material that is increasingly porous, and the parenchyma cell wall will be thinner.[17]

Distribution of the size of the pore radius formed on the activated carbon of bamboo Betung as a result of the 600°C activation process with a holding time of 60 minutes in this study, for each material sample ABR 400, ABR 500, ABR 600, ABR 700 and ABR 800, can be seen sequentially in Figure 4.3.(a – e).

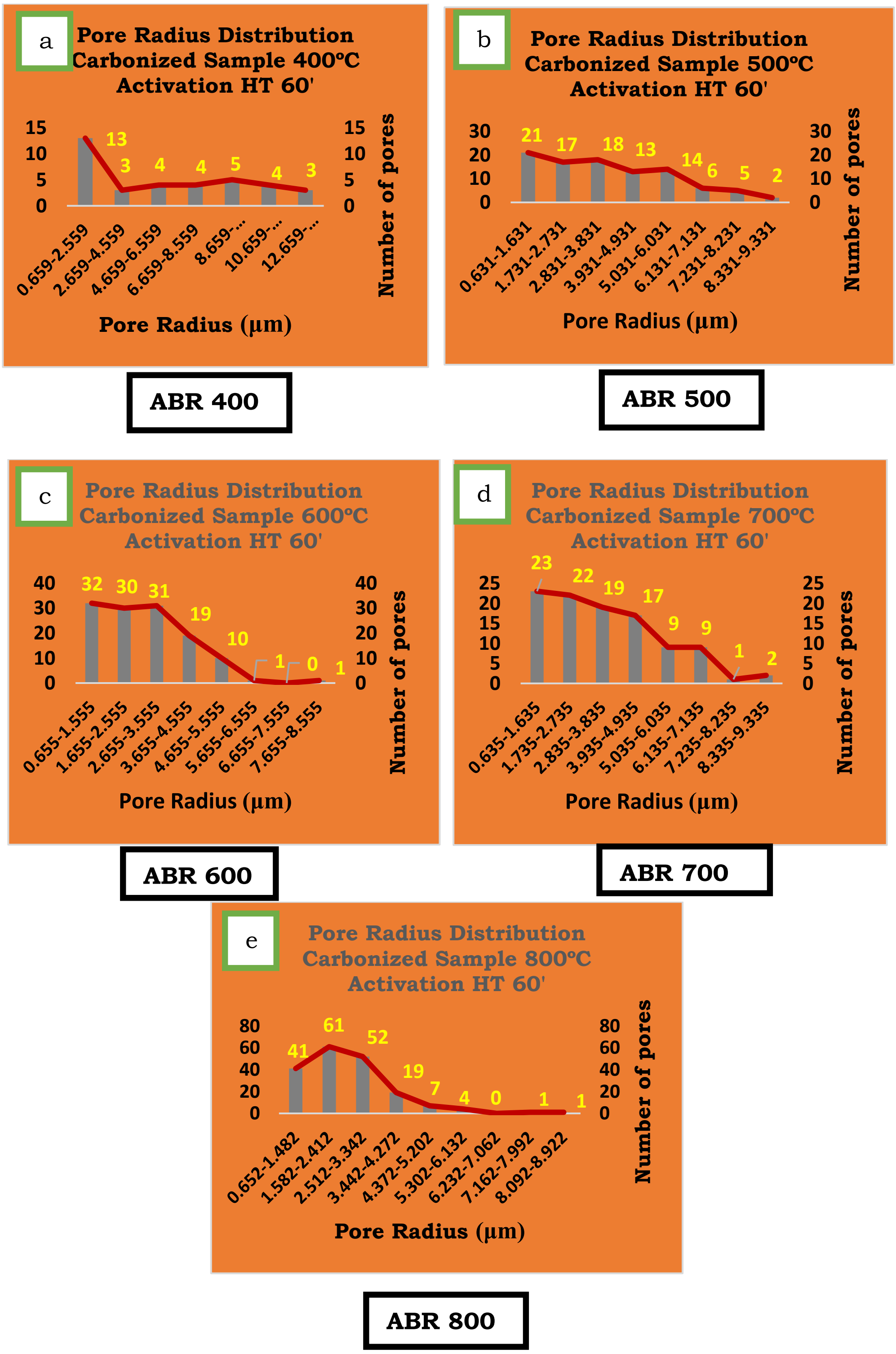


Figure 3. Pore size distribution graph of bamboo Betung activated carbon material

Based on Figure 3, it can be seen that each material sequentially ABR 400, ABR 500, ABR 600, ABR 700, and ABR 800 has a number of pores of 36, 96, 124, 102, and 186 pores, respectively. It can be seen that there is a tendency to increase the number of pores with increasing carbonization temperature. This is probably caused by the increasing number of pores that can be accessed with higher heat penetration, but it does not rule out the possibility of damaged pores so that they become closed and will reduce the number of pores formed. If it may be assumed that the small pore size is a pore size range with a pore size of < 3 m, it can be explained here that the ABR 800 material, in Figure 4.3 (e), with a carbonization temperature of 800^{oC}and an activation of 600^{oC}with a holding time of 60 minutes has the largest number of small pore sizes is 41 small pores. While the ABR 400 material, with a carbonization temperature of 400^{o}C and activation of 600^{o}C with a holding time of 60 minutes, only has 13 small pores. This is the result of higher heat penetration, opening more small pores. Based on the pore size distribution above, can be determined the average pore size for each material is obtained by dividing the total pore size by the resulting number of pores. The results of the average pore size of the material can be seen in table 1.

Table 1. Average pore radius

Material	Σ Pore	Σ Uk.Pore (µm)	Pore Radius (µm)
ABR 400	36	207,38	5,76
ABR 500	96	347,08	3,61
ABR 600	124	331,35	2,67
ABR 700	102	341,83	3,35
ABR 800	186	452,33	2,43

Table 1 shows that the ABR 400 material with a carbonization temperature of 400^{o}C and activation of 600^{o}on average of 5.76 m, While the ABR 800 material with a carbonization temperature of 800^{o}C and activation of 600^{o}C with a holding time of 60 minutes was has been the smallest pore radius with an average of 2.43 µm.

The porosity of the bamboo Betung activated carbon material is the ratio of the pore volume of the material to the total volume of the material. The pore volume is obtained by conducting an absorptivity test on the material, where the material is immersed in water, then the mass of the wet material (Mwet) is weighed, which is then reduced by the mass of the material before being immersed in water (Mdry). From this absorptivity test, the retained water mass (Mrw) in the material will be obtained, which is then multiplied by the specific volume of water to obtain the volume of water retained in the material (retaining water volume, Vrw) where the volume of this water is equal to the volume of water. pore (Vp) of the material (cm^{3}). In some literature, this pore volume is also known as the retaining water volume (Vrw) of the material, which is the ability of the material to hold/accommodate a certain volume of water. Meanwhile, the total material volume (*Vm*) is the product of the dimensions of the length x width x height of the material (cm^3).

The following is written one example of calculations to get the porosity value of the activated carbon material of bamboo betung ABR 400 as follows:
From the test results obtained:

1. Material mass ABR 400 before moistening (dry mass), *Mdry* = 2.16 g
2. Material mass ABR 400 after moistening (wet mass), *Mwet* = 5.14 g
3. Retained water mass (Mrw) in ABR 400 material
= *Mwet* – *Mdry*
= 5.14 g – 2.16 g = 2.98 g
4. Volume of retained water (*Vrw*) on ABR 400 material
= *Mrw* x Volume of water density
= 2.98 gx 1.00296 cm^3/g
= 2.99 cm3 = Pore volume (*Vp*) material
5. Volume of material (*Vm*) = Length (W) x Width (L) x Height (H) material
= 2.16 cm x 2.48 cm x 2.79 cm = 14,946 cm^3
6. $Porosity\ (\varepsilon) = \frac{Vp}{Vm} = \frac{2.99}{14,946} x100\% = 20.01\%$

Table 2. Material porosity

Material	Initial mass (gr)	Final mass (gr)	Water mass restrained (gr)	Water volume/Pore volume (cm^3)	Volume material (cm^3)	Porosity (%)
ABR 400	2,16	5,1416	2,9816	2,99	14,946	20,01
ABR 500	2,46	5,2945	2,8345	2,84	14,869	19,12
ABR 600	1,5	3,141	1,641	1,65	10,129	16,25
ABR 700	2,48	5,5445	3,0645	3,07	13,859	22,18
ABR 800	1,75	3,1557	1,4057	1,41	11,183	12,61

Volume of water type = 1.00296 cm^3/gr

Table 2 shows that the ABR 700 material is carbonized at a temperature of 700°C, and activation of 600°C with a holding time of 60 minutes was able to provide the highest porosity of 22.18%. At the same time, the lowest porosity is produced by ABR 800 material, which is 12.61%.

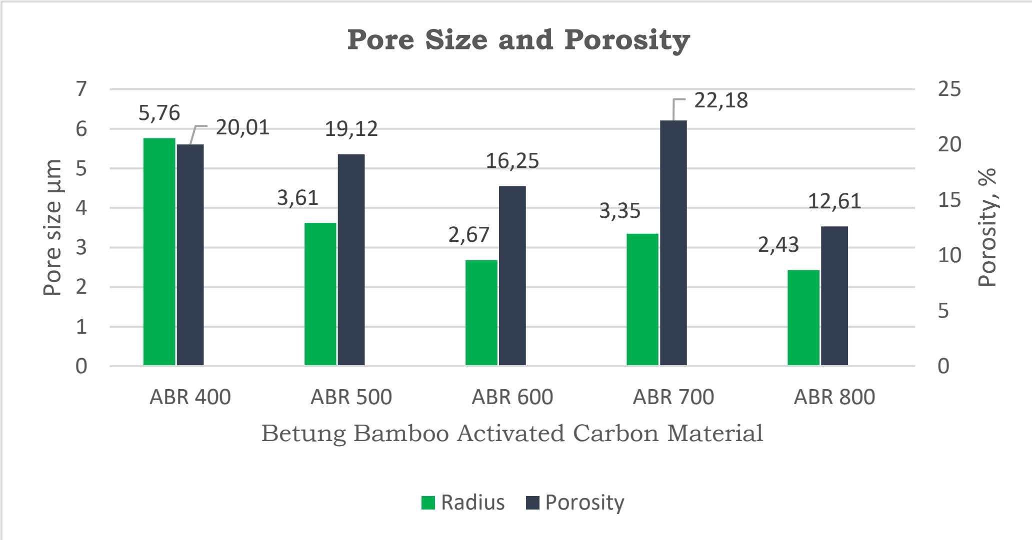


Figure 4. Pore radius graph and porosity of Betung bamboo active carbon material

Figure 4. shows the carbonized ABR 700 material at a temperature of 700°C and activation of 600°C with a holding time of 60 minutes to produce the highest porosity of 22.18% with a pore radius of 3.35 m. As can be seen in Figure 4.3 (d), this is probably due to the fact that the ABR 700 material has a more even distribution of small and large pore sizes, with a large number of pores, namely 102 pores. This also indicates that the ABR 700 material has high porosity based on small pores in a large number of pores. Meanwhile, ABR 800 material has the lowest porosity, which is 12.61%, with a pore radius of 2.43 m. The reason can be seen in Figure 4.3 (e), where the pore size distribution of ABR 800 material is dominated by a small pore size range between 0.652-3,342 m, although it has the largest number of pores, namely 186 pores. It is very likely that the pore size that is too small will be damaged so that it closes the pore and reduces the volume of water that can be accommodated so that the pore volume becomes low, even the lowest compared to other materials, which is only 1.41 cm^3. Porosity is 22.18% in ABR 700 material, meaning that the material has 22.18% voids of the total volume of the material, where the empty space is where water is held/accommodated so that ABR 700 material with 22.18% voids is able to accommodate the volume of water required. At most, that is equal to 3.07 cm^3. In terms of application as a material for a direct evaporative cooling system, it is expected that the material with the highest porosity is expected to accommodate a larger volume of water for a larger evaporation process. High porosity will also greatly affect the permeability of the material.

Permeability is a measure of the ability of the working fluid to flow through narrow spaces (pores) in the material. The amount of permeability can be determined using the equation below;

$$K = \frac{dp^2.\varepsilon^3}{122\ (1-\varepsilon)^2}$$

Furthermore, an example of calculating the permeability of bamboo Betung activated carbon material for ABR 400 material is given below;

$$K = \frac{(1.33x10^{-10}).(0.008)}{122\ (1-0.2)^2} = 1.36 \times 10^{-15}\ m^2$$

Table 3. Material Permeability

Material	Dia.Pore (µm).10^{-6}	Porosity %	Permeability (m^2).10^{-15}
ABR 400	11.5	20.01	13.6
ABR 500	7.24	19.12	4.49
ABR 600	5.36	16.25	1.37
ABR 700	6.70	22.18	6.44
ABR 800	4.86	12.61	0.56

Table 3. showed that ABR 400 material which was carbonized at a temperature of 400°C and activated at 600°C with a holding time of 60 minutes, had the largest pore diameter of 11.5 x 10^{-6} µm and had a porosity of 20.01% smaller than ABR 700 which had a porosity of 22.18%. Despite having a smaller porosity than ABR 700, ABR 400 is able to produce the highest permeability of 13.6x10^{-15} m^2.

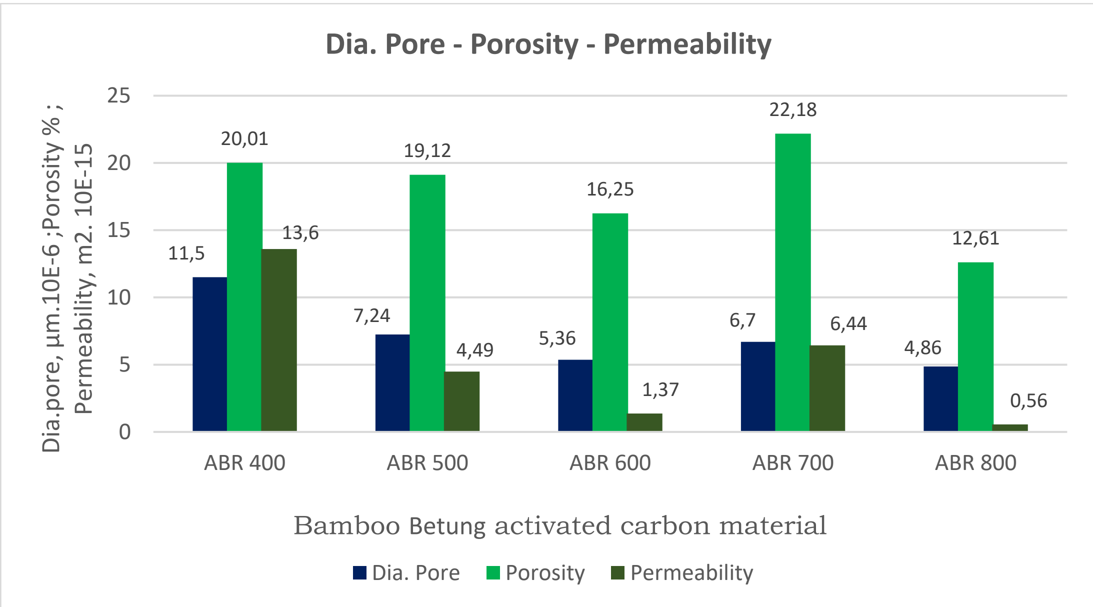


Figure 5. Graph of permeability of carbon active material of bamboo Betung

Figure 5. shows that the ABR 400 material with the largest pore diameter of 11.5x10^{-6} µm and 20.01% porosity was able to produce the highest permeability of 13.6x10^{-15} m^2, compared to ABR 700 material which had a higher porosity of 22.18% but has a smaller pore diameter and is only able to produce a lower permeability of 6.44x10^{-15} m^2. The permeability value of ABR 700 is almost half of the permeability of ABR 400, where although the porosity is higher, the pore diameter is almost half of the pore diameter of ABR 400, which is only 6.7 m. In this case, the pore diameter factor that causes the permeability of ABR 700 is lower than the permeability of ABR 400. On the other hand, the permeability of ABR 700 is higher than the permeability of ABR 500, which has a larger pore diameter than ABR 700, which is 7.24 µm, but the porosity of ABR 500 is lower. Of the porosity of ABR 700, which is 19.12%. Thus, in this case, the porosity factor that causes the permeability of ABR 700 is higher than the permeability of ABR 500. From the two

opposite cases above, it may be assumed that the smaller pore diameter of the material tends to hinder the spread of fluid flowability into the material. However, if the material with a smaller pore diameter has a slightly higher porosity, then it will help expand the spread of fluid into the material because higher porosity has a wider empty space, so the permeability increases. On the other hand, the larger number of small pores produced by the carbonization process at a higher carbonization temperature did not result in the higher permeability of the bamboo Betung activated carbon material. Thus it can be said that the number of pores does not affect the permeability of the bamboo Betung activated carbon material unless the pore size is larger. Higher permeability tends to be produced by materials with larger pore sizes because a larger pore size will provide a wider space for the distribution of the working fluid, and it would be better if it has a fairly high porosity as well.[15-17]

4. **Conclusion**

Bamboo Betung material was carbonized at a temperature of 400^{o}C and activated at a temperature of 600^{o}13.6x10^{-15} m^2 Meanwhile, the lowest permeability was produced by bamboo Betung material which was carbonized at a temperature of 800^{o}C and activated at an activation temperature of 600^{o}only 0.56x10^{-15} m^2

5. References

1. Akintunji LL, Haruna IU, Momoh BS. Theoretical performance analysis of coconut coir as media in evaporative coolers. Int J Sci Tech Res. 2014; 3(3).
2. Berti LF, Santos PHD, Bazzo E, Janssen R, Hotza D. Evaluation of permeability of ceramic wick structures for two phase heat transfer devices. Applied Thermal Eng. 2011; 31(6-7): 1076-81.
3. Boukhanouf R. Investigation of an evaporative cooler for building in hot and dry climate. J Clean Energy Tech. 2014; 2(3).
4. Gislon P, Galli S, Monteleone G. Siloxanes removal from biogas by high surface area adsorbents.Water Manage. 2013; 33: 2687-93.
5. Gunhan T, Demir, V, Yagcioglu AK. Evaluation of the suitability of some local materials as cooling pads. Biosystems Eng. 2007; 96(3): 369-77.
6. Heidarinejad G, Bozorgmehr M, Delfani S, Esmaeelian J. Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions. Building Environ. 2009; 44(10): 2073-9.
7. Huang P, Jhan J, Cheng Y, Cheng H. Effect of carbonization parameters of moso-bamboo based porous charcoal on capturing carbon dioxide. Sci World J. 2014.
8. Jain JK, Hindoliya DA. Experimental performance of new evaporative cooling pad materials. Sustainable Cities Soc. 2011:1(4): 252-6.
9. Kaur V. Preparation and characterisation of charcoal material derived from bamboo for the adsorption of sulphur contaminated water. London J Res Science: Natural Formal. 2018.
10. Liao CM, Chiu KH. Wind tunnel modeling the system performance of alternative evaporative cooling pads in Taiwan region. Building Environ.2002; 37(2): 177-87.
11. Midiani LPI, Septiadi WN, Winaya INS, Sucipta M, Putra N. Characterization of capillary pumping amount in novel sintered zeolites and hybrid zeolite-Cu for heat pipe applications. Int J Heat Mass Transfer. 2019; 145: 118759.
12. Solomon AB, Mahto AK, Joy RC, Rajan AA, Jayprakash DA. Application of bio-wick in compact loop heat pipe. Applied Thermal Eng. 2020; 169: 114927.
13. Wang FY, Wang H, Ma JW. Adsorption of cadmium (II) ions from aqueous solution by a new low-cost adsorbent-Bamboo charcoal. J Hazard Materials. 2010; 177(1-3): 300-6.

14. Wijaksana H, Winaya INS, Sucipta M, Ghurri A. An overview of different indirect and semi-indirect evaporative cooling system for study potency of nanopore skinless bamboo as an evaporative cooling new porous material. J Adv Res Fluid Mechanics Thermal Sci. 2020; 76(3): 109-16.
15. Wu JM, Huang X, Zhang H. Theoretical analysis on heat and mass transfer in a direct evaporative cooler. Applied Thermal Eng, 2009; 29(5-6): 980-4.
16. Zhao X, Liu S, Riffat, SB. Comparative study of heat and mass exchanging materials for indirect evaporative cooling systems. Building Environ. 2008; 43(11): 1902-11.
17. Zhou X, Li L, Dong S, Chen X, Han P. A renewable bamboo carbon/polyaniline composite for a high-performance supercapacitors electrode material. J Solid State Electrochem. 2012; 16: 877-88.