Effect of Carbonization Temperature on Pore Formation and Adsorption Ability of Coconut Shell Activated Carbon with KOH Activator

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Abstract: Activated carbon derived from coconut shells has great potential as an adsorbent for water purification due to its high porosity. This study investigates the effect of carbonization temperature on pore formation and adsorption capacity of coconut shell activated carbon. Carbonization was conducted at temperatures ranging from 500°C to 700°C for 2 hours, followed by chemical activation using 3M KOH solution. The activated carbon was then filtered, washed until neutral pH (± 7), and dried. Characterization was carried out using the BET method to analyze surface area and pore volume, while adsorption capacity was determined using a UV-Vis spectrophotometer with methylene blue as the adsorbate. The results show that increasing the carbonization temperature enhances pore development, as indicated by higher surface area and pore volume. The highest surface area and pore volume were obtained at 700°C, reaching 426.692 m^2/g and 2.414 cc/g, respectively. Correspondingly, the highest adsorption capacity was also observed at 700°C, with a value of 3957.15 mg/g. These findings suggest that carbonization temperature plays a critical role in optimizing the physical characteristics and adsorption performance of coconut shell-based activated carbon.

Keywords: Coconut Shell; Carbonization; Adsorption; KOH Activator.

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I. INTRODUCTION

The growing global population has driven a higher demand for food. In the Asian region, particularly Southeast Asia, coconut production is notably high. Four major countries, namely India, Indonesia, the Philippines, and Sri Lanka, account for approximately 78% of the worlds total coconut production [1]. However, the high level of coconut production also generates a large amount of biomass waste, particularly from unused parts such as shells, husks, and fibers. This waste is often not utilized optimally and ends up as garbage, leading to environmental problems [2]. One promising effort to address this issue is the utilization of coconut waste especially coconut shells as a raw material for the production of activated carbon [3, 4].

Activated carbon can be derived from various carbon-rich raw materials, including coal and biomass waste such as palm fruit bunches, wood, cocoa fiber, coconut shells, coffee husks, and rice husks [5]. Among these, coconut shells are considered a highly suitable precursor due to their high content of carbon, cellulose, hemicellulose, and lignin [6, 7]. These lignocellulosic components play an essential role in determining the quality of the resulting activated carbon, as higher contents of lignin, hemicellulose, and cellulose contribute to better pore development and structural integrity [8].

Activated carbon is a porous solid material composed of 8595% carbon content [9,10]. It is characterized by an extremely high surface area, typically ranging from 100 to 2000 m^2/g [11]. This high surface area results from the presence of abundant micro-porous structures that provide a large number of active sites for adsorption. As a result, activated carbon is widely used in various applications, particularly in water purification, where it serves as an adsorbent for odors, dyes, and dissolved organic compounds [12]. The production of activated carbon generally involves two main stages: carbonization and activation. Carbonization is a thermal decomposition process conducted in the absence or limited presence of oxygen, which removes volatile components and yields a carbon-rich solid residue. This is followed by the activation processeither physical (using steam or inert gases at high temperatures) or chemical (using activating agents such as KOH or $ZnCl_2$)which enhances the pore structure and increases the surface area [13]. This activation is crucial, as the formation of micropores induces capillary effects that significantly improve the adsorption capacity of the carbon.

One of the critical factors influencing the characteristics of activated carbon is the carbonization temperature. The carbonization of lignin at elevated temperatures leads to the release of volatile compounds and the evaporation of lignin, which facilitates the formation of more pores without clogging the gaps between aromatic carbon layers [14]. As the temperature increases, substances that block pore openings are further decomposed, resulting in increased pore formation, higher pore volume, and larger surface area [15,16]. These structural properties, in turn, directly affect the adsorption performance of the activated carbon [17]. Given the importance of these parameters, this study aims to investigate the effect of carbonization temperature (ranging from 500°C to 700°C) on the pore development and adsorption capacity of activated carbon derived from coconut shells. The activation process will be conducted using potassium hydroxide (KOH), and the performance of the activated carbon will be evaluated based on its ability to adsorb methylene blue as a model organic contaminant.

II. METHOD

A. Preparation of Activated Carbon

Coconut shells used as the raw material for activated carbon were first crushed into small pieces and thoroughly cleaned to remove dirt and coconut fibers. The shells were then sun-dried for 3 days until completely dry. Carbonization was performed using a furnace at temperatures of 500, 600, and 700°C for 2 hours, following previous studies [18-20] The resulting charcoal was ground using a mortar and pestle to obtain a fine powder and then sieved using a 40-mesh sieve to ensure uniform particle size.

B. Chemical Activation of Carbon

Chemical activation was carried out using 3M KOH solution. A total of 15 grams of KOH was dissolved in 89.28 mL of distilled water and stirred with a magnetic stirrer for 15 minutes. The carbon powder was mixed with the KOH solution in a 1:1 weight ratio and stirred at 80°C for 1 hour. The activated carbon was then filtered and dried in an oven at 130°C for 4 hours [21]. After activation, the carbon was washed with distilled water until a neutral pH (± 7) was reached. After washing, the activated carbon was dried again in an oven at 120°C for 4 hours to ensure minimal moisture content in the sample [21]. The resulting activated carbon samples were labeled KA500, KA600, and KA700 based on the initial carbonization temperature variations of 500, , and 700°C, respectively.

C. Characterization of Activated Carbon

Each sample (KA500, KA600, KA700) was characterized by weighing 1 gram of activated carbon powder and analyzing it using the *BrunauerEmmettTeller* (BET) method to determine surface area and pore volume.

D. Adsorption Test Using Methylene Blue

The adsorption capacity was evaluated using methylene blue (MB) dye solution. 100 ppm MB solution was prepared by dissolving the dye in 20 mL of distilled water. Then, 20 grams of activated carbon powder was added to the solution and stirred using a magnetic stirrer at 100 rpm for 150 minutes. Samples of 4 mL were taken at different contact times (30, 60, 90, 120, and 150 minutes).

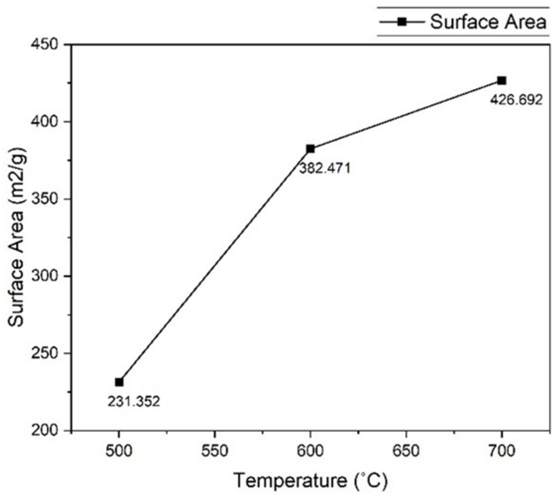

FIG. 1: Graph of the relationship between carbonization temperature and surface area of coconut shell activated carbon.

From each sample, 1 mL was pipetted and analyzed using a UV-Vis spectrophotometer to measure absorbance. These absorbance values were compared with the initial MB solution (before the addition of activated carbon) to determine the remaining dye concentration. The adsorption capacity (Q) was calculated using the following equation:

$$Q = \left(\frac{C_\circ - C_1}{m} \right) V \tag{1}$$

where Q = adsorption capacity (mg/g), $C_\circ$ = initial dye concentration (ppm), C_1 = dye concentration after adsorption (ppm), V = volume of the dye solution (L), m = mass of the adsorbent (g).

A standard calibration curve (absorbance vs. concentration) was also established to accurately determine the dye concentration after adsorption.

III. RESULTS AND DISCUSSION

The surface area of the adsorbent plays a critical role in determining its adsorption performance. Activated carbon is considered an effective adsorbent when it possesses a high surface area [22]. As shown in Fig. 1, the surface area of coconut shell-based activated carbon is influenced by the carbonization temperature. The lowest surface area was recorded for sample KA500 at 231.352 m^2/g, while the highest was observed in KA700 at 426.692 m^2/g.

The relatively low surface area of KA500 can be attributed to insufficient pore development at lower carbonization temperatures. At these temperatures, a significant amount of

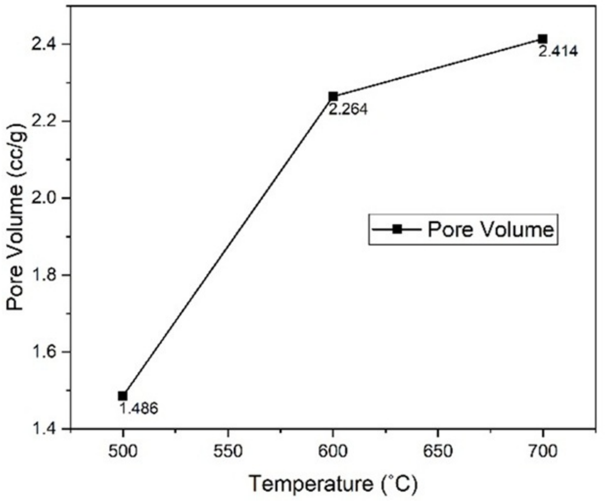

FIG. 2: Graph of the relationship between carbonization temperature and pore volume of coconut shell activated carbon.

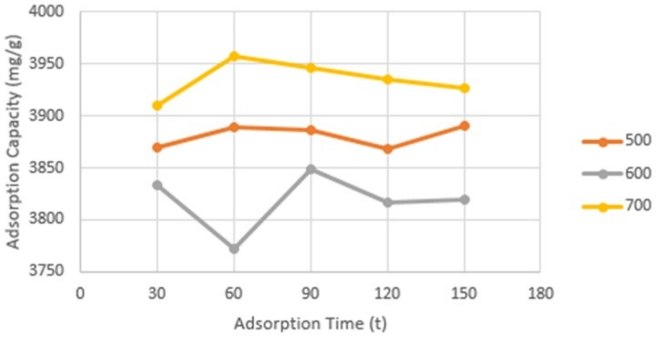

FIG. 3: Graph of the relationship between contact time and adsorption capacity.

volatile matter remains, and tar residues tend to block the pore structure, inhibiting the formation and expansion of new pores [23]. This results in a reduced number of active sites available for adsorption. Conversely, higher carbonization temperatures promote the release of volatile components and facilitate the development of micropores, thereby increasing the specific surface area of the activated carbon [24]. These findings are consistent with previous studies which demonstrated that elevated carbonization temperatures enhance surface area due to more complete thermal decomposition and greater porosity formation [24,25].

Carbonization temperature also significantly affects the pore volume of activated carbon, as depicted in Fig. 2. The highest pore volume was achieved by KA700 at 2.414 cc/g, while KA500 exhibited the lowest value at 1.486 cc/g. An increase in carbonization temperature leads to greater pore development, driven by the evaporation of volatile compounds during pyrolysis [26]. During carbonization, the decomposition of cellulose, hemicellulose, and lignin results in dehydration and subsequent polymerization, forming a carbon matrix. As the temperature increases, this polymerization process intensifies, facilitating the expansion of pores and contributing to a higher surface area and pore volume [24].

These structural characteristics directly influence adsorption performance. As illustrated in Fig. 3, the highest adsorption capacity was obtained by KA700, reaching 3926.84 mg/g. This confirms that carbonization temperature significantly affects the adsorption capacity of activated carbon. One of the main contributing factors is the increased surface area at higher temperatures, which offers more active sites for adsorbate interaction [27]. Several studies have reported a positive correlation between increased carbonization temperature, surface area, and adsorption capacity [17], [28]. The formation of well-structured pores and more complete removal of volatile materials at higher temperatures contribute to this improvement [29].

The adsorption behavior over time, as shown in Fig. 3, initially increases and then decreases. Significant adsorption was observed at 30 and 60 minutes for both KA500 and KA700. This initial phase is marked by high adsorption rates due to the availability of unoccupied pores that readily trap adsorbate molecules [17]. In general, longer contact time enhances adsorption until equilibrium is reached, at which point the adsorbent can no longer retain additional adsorbate [30,31].

A decrease in adsorption capacity was observed for KA500 at 90 and 120 minutes, which can be attributed to saturation of the adsorbent surface, leading to desorption. In this process, some of the previously adsorbed molecules are released back into the solution, reducing the overall adsorption performance [32]. Interestingly, a slight increase in adsorption capacity was noted again at 150 minutes for KA500. This phenomenon may be explained by the reversible nature of the adsorption process, wherein desorbed molecules can be re-adsorbed, allowing the activated carbon to regain part of its adsorption capability [33].

IV. CONCLUSION

This study demonstrates that carbonization temperature has a significant impact on the physical characteristics of activated carbon and its performance as an adsorbent. Activated carbon derived from coconut shell carbonized at 700°C (KA700) exhibited the highest surface area and pore volume, measuring 426.692m^2/g and 2.414cc/g, respectively. The increase in carbonization temperature promotes more developed pore structures due to more complete decomposition of volatile compounds. These characteristics directly influence adsorption capacity, with KA700 achieving the highest value at 3926.84mg/g. The adsorption process is also affected by contact time, where adsorption increases during the initial phase and reaches equilibrium over time. A decrease in adsorption capacity at certain contact times indicates desorption, while a subsequent increase at longer contact times suggests the possible reversible nature of activated carbon.

[1] A.I. Bakti, P.L. Gareso, and N. Rauf, ”Characterization of Active Carbon from Coconut Shell using X-Ray Diffraction (X-RD) and SEM-EDX Techniques,” J. Penelit. Fis. dan Apl., vol. 8, no. 2, p. 115, 2018, doi: 10.26740/jpfa.v8n2.p115-122.

[2] W.M.A.W. Daud, W.S.W. Ali, and M.Z. Sulaiman, ”Effects of carbonization temperature on pore development in palm-shell-based activated carbon,” Carbon N. Y., vol. 38, no. 14, p. 1925-1932, 2000, doi: 10.1016/S0008-6223(00)00028-2.

[3] A.R. Hidayu, and N. Muda, ”Preparation and Characterization of Impregnated Activated Carbon from Palm Kernel Shell and Coconut Shell for CO2 Capture,” Procedia Eng., vol. 148, p. 106-113, 2016, doi: 10.1016/j.proeng.2016.06.463.

[4] D. Das, D.P. Samal, and M. BC, ”Preparation of Activated Carbon from Green Coconut Shell and its Characterization,” J. Chem. Eng. Process Technol., vol. 06, no. 05, 2015

[5] H.D. Febrianto, Pramahadi, Jerry, Arysca Wisnu Satria, ”Pembuatan dan Karakterisasi Karbon Aktif Berbahan Baku Limbah Kulit Durian sebagai Elektroda Superkapasitor,” Integr. Proses, vol. 8, no. 1, p. 19-24, 2019.

[6] D. Tamado, *et al.*, ”Sifat Termal Karbon Aktif Berbahan Arang Tempurung Kelapa,” Semin. Nas. Fis., p. 73-81, 2013.

[7] A. Eko and A. Perdana, ”Pelunakan tempurung Kelapa Dengan Proses Kimiawi Untuk Bahan Baku Kerajinan Tangan,” Pros. Semin. Nas. Kim. dan Pendidik. Kim. XII (SN-KPK XII) https//jurnal.uns.ac.id/snkpk Hal 128-135 PELUNAKAN, pp. 128135, 2021.

[8] H. Nurdiansah and D. Susanti, ”Pengaruh Variasi Temperatur Karbonisasi dan Karbon Aktif Tempurung Kelapa dan Kapasitansi Electric Double Layer Capacitor,” J. Tek. Pomits, vol. 2, no. 1, pp. 13-18, 2013.

[9] R. Idrus, B.P. Lapanporo, and Y.S. Putra, ”Pengaruh Suhu Aktivasi Terhadap Kualitas Karbon Aktif Berbahan Dasar Tempurung Kelapa,” Prism. Fis., vol. 1, no. 1, p. 4, 2013.

[10] A. Syamboga and A. Budianto, ”Review Karakterisasi Karbon Aktif dari Berbagai Jenis Serbuk Kayu,” J. Tecnoscienza, vol. 6, no. 1, p. 1-12, 2021, doi: 10.51158/tecnoscienza.v6i1.443.

[11] Y.W. Hydhayat, and K. Surabaya, Karbon Aktif dari Limbah Daun Jati menggunakan Aktivator Larutan KOH,” Tek. Kim., vol. 16, no. 2, p. 87-92, 2022.

[12] M. Puspita, M.L. Firdaus, and Nurhamidah, ”Pemanfaatan Arang Aktif Sabut Kelapa Sawit Sebagai Adsoben Zat Warna Sintetis Reactive Red-120 Dan Direct Green -26,” Alotrop, vol. 1, no. 1, p. 75-79, 2017.

[13] Yustinah, and Hartini, ”Adsorbsi Minyak Goreng Bekas Menggunakan Arang Aktif dari Sabut Kelapa,” in Pengembangan Teknologi Kimia untuk Pengolahan Sumber Daya Alam Indonesia, 2011, p. B05-1-B05-5.

[14] G. Pari, K. Sofyan, W. Syafii, Buchari, and H. Yamamoto, ”Kajian Struktur Arang dari Lignin,” J. Penelit. Has. Hutan, vol. 24, no. 1, p. 9-20, 2006.

[15] F.C. Hidayati, Masturi, and I. Yulianti, ”Pemurnian Minyak Goreng Bekas Pakai (Jelantah) dengan Menggunakan Arang Bonggol Jagung,” JIPF (Jurnal Ilmu Pendidik. Fis., vol. 1, no. 2, p. 67, 2016, doi: 10.26737/jipf.v1i2.67.

[16] H. Demiral, *et al.*, ”Pore Structure of Activated Carbon Prepared From Hazelnut Bagasse by Chemical Activation,” Surf. Interface Anal., vol. 40, no. 3-4, p. 616619, 2008

[17] L.E. Laos, and A. Selan, ”Pemanfaatan Kulit Singkong sebagai Bahan Baku Karbon Aktif,” J. Teknol. Kim. Unimal, vol. 1, p. 32-36, 2016, doi: 10.29103/jtku.v4i2.69.

[18] L. Maulinda, N. ZA, and D.N. Sari, ”Pemanfaatan Kulit Singkong sebagai Bahan Baku Karbon Aktif,” J. Ilmu Pendidik. Fis., vol. 4, no. 2, p. 11-19, 2016.

[19] F. Hanum, R. J. Gultom, and M. Simanjuntak, ”Adsropsi Zat Warna Metilen Biru Dengan Karbon Aktif Dari Kulit Durian Menggunakan KOH Dan NaOH Sebagai Aktivator,” J. Tek. Kim. USU, vol. 6, no. 1, p. 49-55, 2017.

[20] A. Budianto, Romiarto, and Fitrianingtyas, ”Pemanfaatan Limbah Kakao (Theobroma cacao L) sebagai Karbon Aktif dengan Aktivator Termal dan Kimia,” Semin. Nas. Sains dan Teknol. Terap. Inst. Teknol. Adhi Tama Surabaya, p. 207-212, 2016.

[21] H.R. Suryadi, *et al.*, ”Pengaruh jenis aktivator terhadap nilai kapasitansi elektroda karbon dari tempurung kelapa - The influence of activator types on the capacitance value of carbon electrodes from coconut shell,” J. Aceh Phys.Soc, vol. 11, no. 2, p. 52-58, 2022, doi: 10.24815/jacps.v11i2.23789.

[22] M. Sudibandriyo, and Lydia, ”Karakteristik Luas Permukaan Karbon Aktif dari Ampas Tebu dengan Aktivasi Kimia,” J. Tek. Kim. Indones., vol. 10, no. 3, p. 149-156,

[23] P.-H. Huang, *et al.*, ”Effects of Carbonization Parameters of MosoBambooBased Porous Charcoal on Capturing Carbon Dioxide,” Sci. World J., 2014.

[24] W. Li, *et al.*, ”Effects of Carbonization Temperatures on Characteristics of Porosity in Coconut Shell Chars and Activated Carbons Derived from Carbonized Coconut Shell Chars,” Ind. Crops Prod., vol. 28, no. 2, p. 190-198, 2008, doi: 10.1016/j.indcrop.2008.02.012.

[25] J. Jamal, I. Safitri, and N. Yutia, ”Pemanfaatan Karbon Aktif Batang Sagu yang Diaktivasi Menggunakan Microwave sebagai Media Filter pada Penurunan Kadar Besi (Fe), Mangan (Mn) dan Kekeruhan Air Sumur Gali,” JIIP - J. Ilm. Ilmu Pendidik., vol. 5, no. 9, p. 3358-3365, 2022, doi: 10.54371/jiip.v5i9.867.

[26] J. Katesa, S. Junpiromand, and C. Tangsathitkulchai, ”Effect of Carbonization Temperature on Properties of Char and Activated Carbon from Coconut Shell,” Suranaree J. Sci. Technol, vol. 20, no. 4, p. 269-278, 2013.

[27] R.W. Putri, S. Haryati, and Rahmatullah, ”Pengaruh Suhu Karbonisasi Terhadap Kualitas Karbon Aktif dari Limbah Ampas Tebu,” J. Tek. Kim., vol. 25, no. 1, p. 1-4, 2019.

[28] Sirajuddin, Harjanto, and A.D. Agustin, ”Pengaruh Temperatur Karbonisasi Terhadap Karakteristik Arang Aktif dari Tempurung Kluwak (Pangium Edule),” Pros. 4 Semin. Nasionall Penelit. Pengabdi. Kpd. Masy., p. 60-64, 2020.

[29] Desi, A. Suharman, and R. Vinsiah, ”Pengaruh Variasi Suhu Karbonisasi terhadap Daya Serap Karbon Aktif Cangkang Kulit Buah Karet (Hevea brasilliensis),” Pros. SEMIRATA, p. 294-303, 2015.

[30] D.A. Pratama, ”Efektivitas Ampas Teh Sebagai Adsorben Alternatif Logam Fe dan Cu pada Air Sungai Mahakam,” J. Integr. Proses, vol. 6, no. 3, p. 131-138, 2017

[31] M.F.P. Sari, P. Loekitowati, and R. Mohadi, ”Penggunaan Karbon Aktif Dari Ampas Tebu Sebagai Adsorben Zat Warna Procion Merah Limbah Cair Industri Songket,” J. Nat. Resour. Environ. Manag., vol. 7, no. 1, p. 37-40, 2017, doi: 10.19081/jpsl.2017.7.1.37.

[32] L.W. Hadayani, I. Riwayati, and R.D. Ratnani, ”Adsorpsi Pewarna Metilen Biru Menggunakan Senyawa Xanthat Pulpa Kopi,” Momentum, vol. 11, no. 1, p. 19-23, 2015.

[33] G.I. Hayati, B. Pertiwi, and Y. Ristianingsih, ”Pengaruh Variasi Konsentrasi Adsorben Biji Trembesi Terhadap Penurunan Kadar Logam Kromium (Cr) Total pada Limbah Indusri Sasirangan,” Konversi, vol. 5, no. 2, p. 1, 2016