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Effects of Calcination Temperature on Physicochemical Properties of Durian Shell-Derived Activated Carbon Materials

Ảnh hưởng của nhiệt độ nung đến đặc tính hóa lý của than hoạt tính có nguồn gốc từ vỏ quả sầu riêng

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Abstract

Although durian has become a major agricultural commodity and a leading contributor to Vietnam's fruit and vegetable export revenue, the resulting durian shell waste poses significant environmental challenges, including odor emissions, pest proliferation, and environmental pollution. Herein, durian shell biomass is efficiently converted into activated carbon materials through a combined hydrothermal carbonization and pyrolysis strategy. The influence of calcination temperature on the characteristics of durian shell-derived activated carbon is systematically investigated using various analytical techniques. Experimental results reveal the critical role of treatment temperature in governing the resulting physicochemical characteristics of durian shell-derived activated carbon materials. Among the investigated samples, the activated carbon produced at 800 °C shows the largest surface area (737.03m^2 g^{-1}) and a mesoporous structure, suggesting its potential suitability for diverse applications, including photocatalysis and electrocatalysis. These findings provide valuable insights into the temperature-dependent structure–property relationships of durian shell-derived

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activated carbon and offer a rational basis for developing advanced biomass-derived carbon materials while simultaneously contributing to the valorization of durian waste and mitigation of its associated environmental challenges.

Keywords: pyrolysis preparation, biochar, durian shell, activated carbon, electrocatalysis

Tóm tắt

Cây sầu riêng hiện nay đã trở thành mặt hàng nông sản chủ lực và đóng góp quan trọng vào kim ngạch xuất khẩu rau quả của Việt Nam, nhưng lượng vỏ sầu riêng thải ra đã đặt ra những thách thức lớn về môi trường, bao gồm vấn đề mùi hôi, sự gia tăng của côn trùng gây hại và ô nhiễm môi trường.Trong nghiên cứu này, sinh khối vỏ sầu riêng được chuyển đổi hiệu quả thành than hoạt tính thông qua phương pháp kết hợp giữa quá trình cacbon hóa thủy nhiệt và nhiệt phân. Sự ảnh hưởng của nhiệt độ tổng hợp đến các tính chất đặc trưng của than hoạt tính từ vỏ sầu riêng đã được khảo sát một cách hệ thống bằng nhiều kỹ thuật phân tích khác nhau. Kết quả thực nghiệm cho thấy vai trò then chốt của nhiệt độ nhiệt phân đối với các tính chất lý hóa của than hoạt tính được tổng hợp từ vỏ sầu riêng. Trong số các mẫu được khảo sát, than hoạt tính được tổng hợp tại 800°C có diện tích bề mặt lớn nhất (737,03m^2 g^{-1}) với cấu trúc lỗ xốp mesoporous, cho thấy tiềm năng ứng dụng đa dạng cho quang xúc tác và điện xúc tác. Những kết quả này chỉ ra sự phụ thuộc đáng kể của cấu trúc vào nhiệt độ xử lý, góp phần làm cơ sở khoa học để tổng hợp các vật liệu carbon tiên tiến từ sinh khối.

Từ khóa: phương pháp nhiệt phân, sinh khối, vỏ quả sầu riêng, than hoạt tính, xúc tác điện hóa

1. Introduction

Durian (*Durio zibethinus L.*) is a commercially important tropical fruit cultivated extensively across Southeast Asia, particularly in Vietnam, Thailand, Malaysia, and Indonesia [1-3]. According to the Vietnam Fruit and Vegetable Association, durian has emerged as a key agricultural commodity and is currently the largest contributor to the country's fruit and vegetable export revenue, with the sector expected to generate about USD 4 billion in 2026. Vietnam produces approximately 642,000 tons of durian annually, and the increasing consumption and processing of this fruit inevitably generate substantial quantities of solid biomass waste, as the peel accounts for approximately 70–75% of the total fruit mass [1, 4, 5]. The increasing accumulation of durian peel waste has become a growing environmental concern because its treatment remains largely dependent on conventional disposal practices, including landfilling, open dumping, and uncontrolled combustion, which cause unpleasant odors, promote pest proliferation, and contribute to the release of potentially harmful pollutants into the surrounding environment [1, 6]. Thus, valorizing durian peel into value-added materials provides a sustainable pathway for mitigating biomass waste while simultaneously improving the environmental and economic sustainability of the durian industry.

With its high content of cellulose (60.5%), hemicellulose (13.1%), and lignin (15.4%), durian shell waste is a potential lignocellulosic feedstock for fabricating value-added carbonaceous materials [2, 7-11]. For instance, Pham et al. [9] successfully fabricated activated carbon materials from durian peel through a carbonization process at 600^{o}C using phosphoric acid solution as a chemical activation agent. The resulting material showed an ammonium-ion adsorption capacity of 12.56 mg g^{-1}. Ninh et al.[10] employed KOH as an activating agent for fabricating the durian shell-derived activated carbon via pyrolysis at 700 ^{o}C. The resulting activated carbon showed a surface area of 583 m^2 g^{-1} and achieved an adsorption capacity of 96.7 mg g^{-1} for methylene blue. This value was substantially higher than those reported for commercial activated carbon (43.3 mg g^{-1}), bamboo-derived activated carbon (31.54–48.29 mg g^{-1}), and *Mimosa pigra*-derived biochar (20.18 mg g^{-1}) in previous studies. Despite these advances, the temperature-dependent evolution of the structural and physicochemical characteristics of durian shell-derived activated carbon remains insufficiently understood.

Therefore, a systematic investigation of the temperature-dependent structural evolution of activated carbon is warranted to establish the relationship between processing temperature and material properties for rationally designing high-efficiency biomass-derived carbon materials.

Inspired by the aforementioned considerations, we herein systematically investigate the effects of calcination temperature on the structural and morphological characteristics of durian shell-derived activated carbon materials prepared through a combined hydrothermal carbonization and pyrolysis strategy. The resulting materials are comprehensively characterized using X-ray diffraction (XRD), Raman spectroscopy, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDX), and Brunauer–Emmett–Teller (BET) nitrogen adsorption–desorption analysis. Experimental results demonstrate that calcination temperature is crucial for governing the structural evolution of durian shell-derived activated carbon materials. Notably, the sample prepared at 800°C exhibits the largest surface area of 737.03m^2 g^{-1} and a predominantly mesoporous structure, highlighting the potential of temperature-controlled thermal treatment to modify the resulting characteristics of durian shell-derived activated carbon materials for potential applications, such as environmental remediation and electrochemical energy conversion.

2. Experiments

2.1. Chemicals

All chemicals, including sulfuric acid (H_2SO_4, 98%, Merck) and potassium hydroxide (KOH, 85%, Merck) were used without further purification. Durian shell (DS) was collected from Tan Phu district, Dong Nai province, and was used as the starting biomass for fabricating activated carbon.

2.2. Fabrication of durian shell-derived activated carbon materials

Durian shell-derived activated carbon materials were fabricated via hydrothermal carbonization and calcination strategies [12]. Briefly, durian shells (DSs) were thoroughly cleaned with water to eliminate adhering impurities, sliced, and dried at 120 ºC. The dried DSs were subsequently pulverized into a fine powder (GPs), which served as the biomass precursor for hydrothermal carbonization. In a typical synthesis, 25 g of GPs was dispersed in 50 mL of 10 wt% H_2SO_4 solution and was hydrothermally carbonized at 160°C for 12 h. The obtained hydrochar was thoroughly cleaned with deionized water and recovered by vacuum filtration. After drying at 120°C, 5 g of the as-made hydrochar was mixed with KOH at a predetermined hydrochar/KOH mass ratio. The mixture was thermally treated under a continuous N_2 atmosphere at different temperatures (600, 700, 800, and 900ºC), as denoted AC_600, AC_700, AC_800, and AC_900, respectively. Finally, the products were cleaned with deionized water and then dried at 80°C.

2.3. Material characterizations

The crystalline information of specimens was collected through XRD on a D2 PHASER (Bruker, Germany) using Cu Kα radiation at 0.02º step size in the 2-theta range from 20 to 80º. The structural behavior of activated carbon was further probed by room-temperature Raman scattering measurements on a SPELECRAMAN532 device (Metrohm DropSens, Spain) with a laser source of 532 nm in the wavenumber range from 1000 to 2000 cm^{-1}. The morphology and elemental composition of the samples were characterized by scanning electron microscopy coupled with energy-

dispersive X-ray spectroscopy (SEM–EDX) using a Thermo Scientific Axia ChemiSEM system (Thermo Fisher Scientific, USA) operated at an accelerating voltage of 10 kV. The surface area was determined by N_2 adsorption–desorption isotherms at 77 K on a Quantachrome NOVA 1000e analyzer (Quantachrome Corporation, USA). Before BET measurements, the samples were degassed at 250 °C for 3 h under vacuum to remove physisorbed water and other volatile species from the sample surfaces.

3. Results and discussion



Figure 1. A photograph of (a) sliced durian shell, (b) ground durian shells, (c) hydrochar material after the hydrothermal carbonization process at 160ºC for 12 h in 10 w/v% H_2SO_4 aqueous solution, and (d) activated carbon after the calcination process at 800ºC.

The durian shell-derived activated carbon materials were synthesised through hydrothermal carbonization and pyrolysis strategies. Figure 1 shows the colors of sliced durian shell, ground durian shell powder, hydrochar, and activated carbon material during the fabrication procedure. The change in structural characteristics of materials before and after the pyrolysis process was determined by XRD analysis in the 2-theta range of 10–80º. As shown in Figure 2a-f, XRD patterns of materials reveal that a broad diffraction peak in the 2-theta range from 20–30º corresponded to (002) planes, which is a characteristic diffraction peak of carbon materials. After pyrolysis, another peak was observed in the 2-theta range from 40–50º of the (100) plane, which was associated with the hexagonal graphitic peak. A similar trend was described for almost all biomass-derived activated carbon materials, demonstrating that the durian shell biomass was successfully converted into activated carbon [13-15].

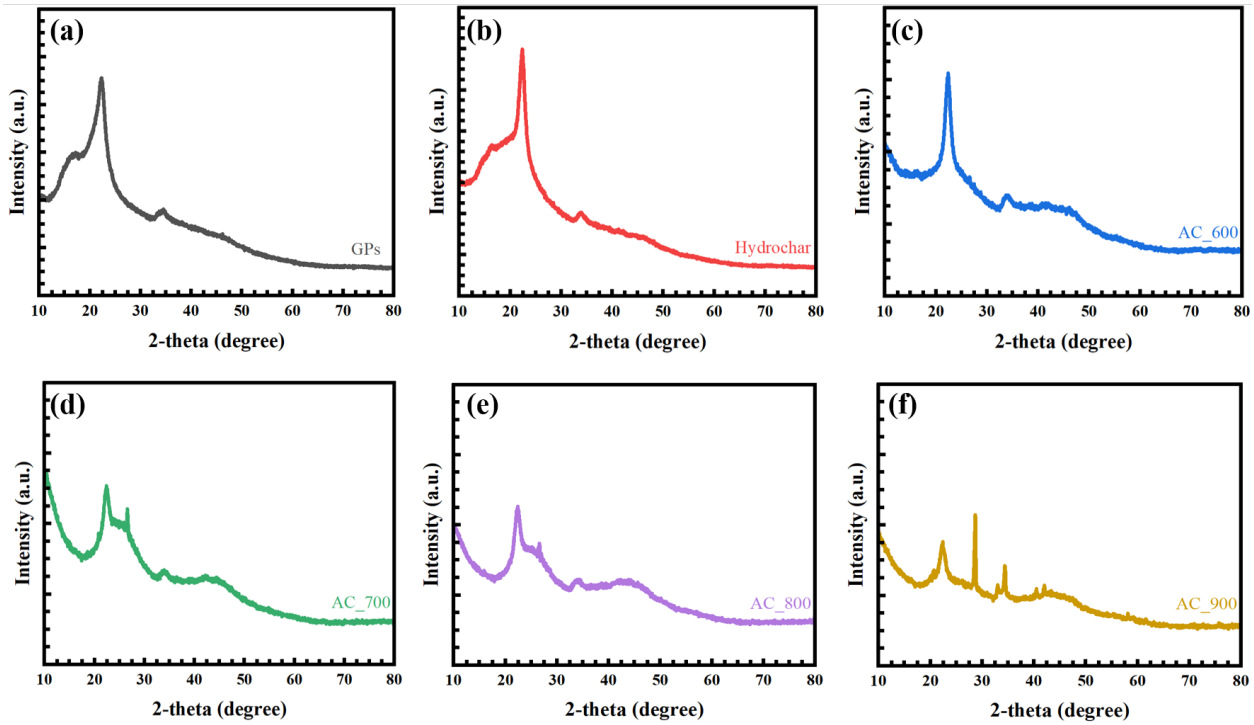


Figure 2. X-ray diffraction patterns in the 2-theta range from 10 to 80° at a step size of 0.02° of (a) ground durian shell, (b) hydrochar, (c) AC_600, (d) AC_700, (e) AC_800, and (f) AC_900.

The structural characteristics of as-made durian shell-derived activated carbon materials were further probed by Raman spectroscopy, which offered more information associated with the carbon atoms bonded in a diamond-like (sp^3, D-band) and graphite-like (sp^2, G-band) configurations. In addition, the D-band mode was due to disorder or defects in a graphitic structure with $A1_g$ symmetry, while the G-band was associated with an E_{2g} in-plane vibration of sp^2 bonds of carbon in the graphite lattice mode [16, 17]. As illustrated in Figure 3, room-temperature Raman spectra of the studied materials exhibited typical vibration modes of carbon-based materials, with two Raman peaks at ~1400 and ~1600 cm^{-1} for the D- and G-bands, respectively. In addition, the calculated I_D/I_G ratio of as-prepared activated carbon increased with increasing calcination temperature from 600 to 800°C (0.54 < 0.83 < 0.90), indicating a higher density of defect sites within the carbon framework. However, upon further increasing the calcination temperature to 900 °C, the I_D/I_G ratio decreased to 0.73, suggesting partial structural reorganization and an increased degree of graphitic ordering at the higher calcination temperature. This is consistent with the findings reported by El-Shabasy's group [17]. Collectively, XRD and Raman results demonstrate that calcination temperature plays an important role in regulating the structural defects of durian shell-derived activated carbon.

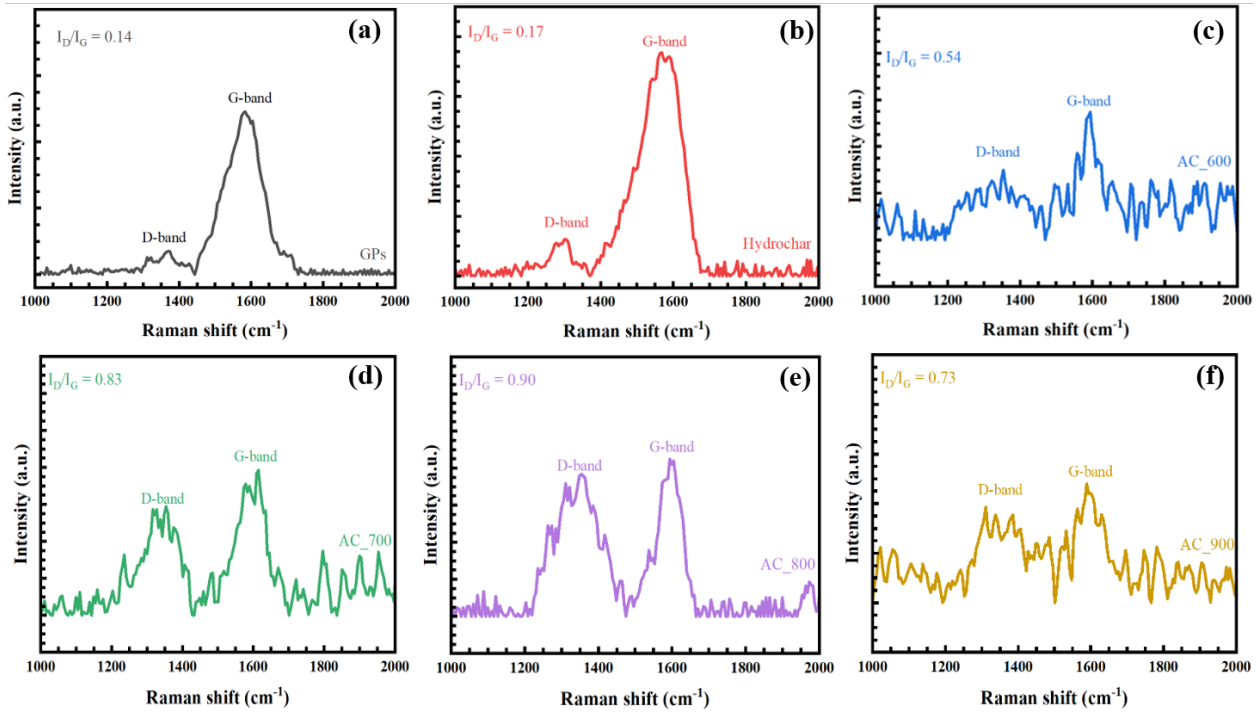


Figure 3. Raman spectroscopy in the wavenumber range from 1000 to 2000 cm^{-1} of (a) ground durian shell, (b) hydrochar, (c) AC_600, (d) AC_700, (e) AC_800, and (f) AC_900 materials.

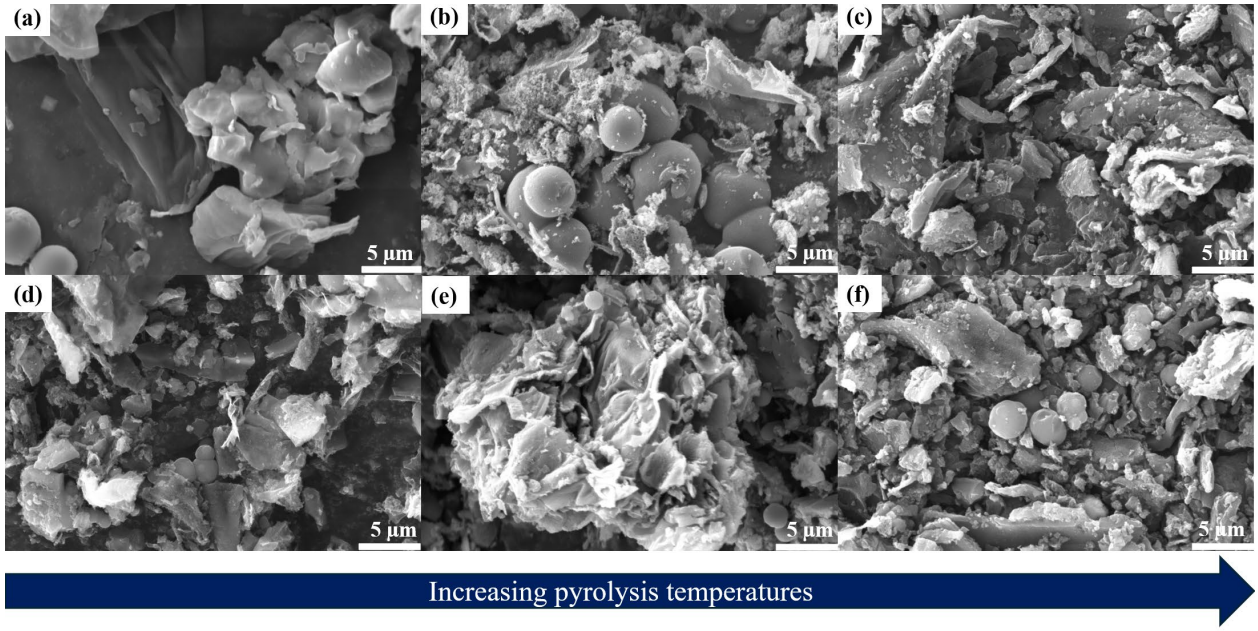


Figure 4. Field emission scanning electron microscopy (FE-SEM) images at 5 µm scale bar of (a) ground durian shell, (b) hydrochar, (c) AC_600, (d) AC_700, (e) AC_800, and (f) AC_900.

Figure 4 shows FE-SEM images at a scale bar of 5 µm of all studied materials, demonstrating that durian shell-derived activated carbon exhibited a reduction in particle size while an increase in the presence of fragmented structures compared to ground durian shell and hydrochar materials. This phenomenon was attributed to the etching effect of KOH on the carbon skeleton and precursor at elevated calcination temperature, resulting in the facilitated release of volatile components and subsequent disruption of the original microstructure and

thereby increasing the specific surface area of activated carbon materials [18]. The EDX elemental mapping images also indicated that the carbon content increased from 47.7 wt% (GPs) to 69.6 wt% (AC_800), as illustrated in Figure 5, indicating that the pyrolysis strategy efficiently converted durian shell biomass into activated carbon with high purity.

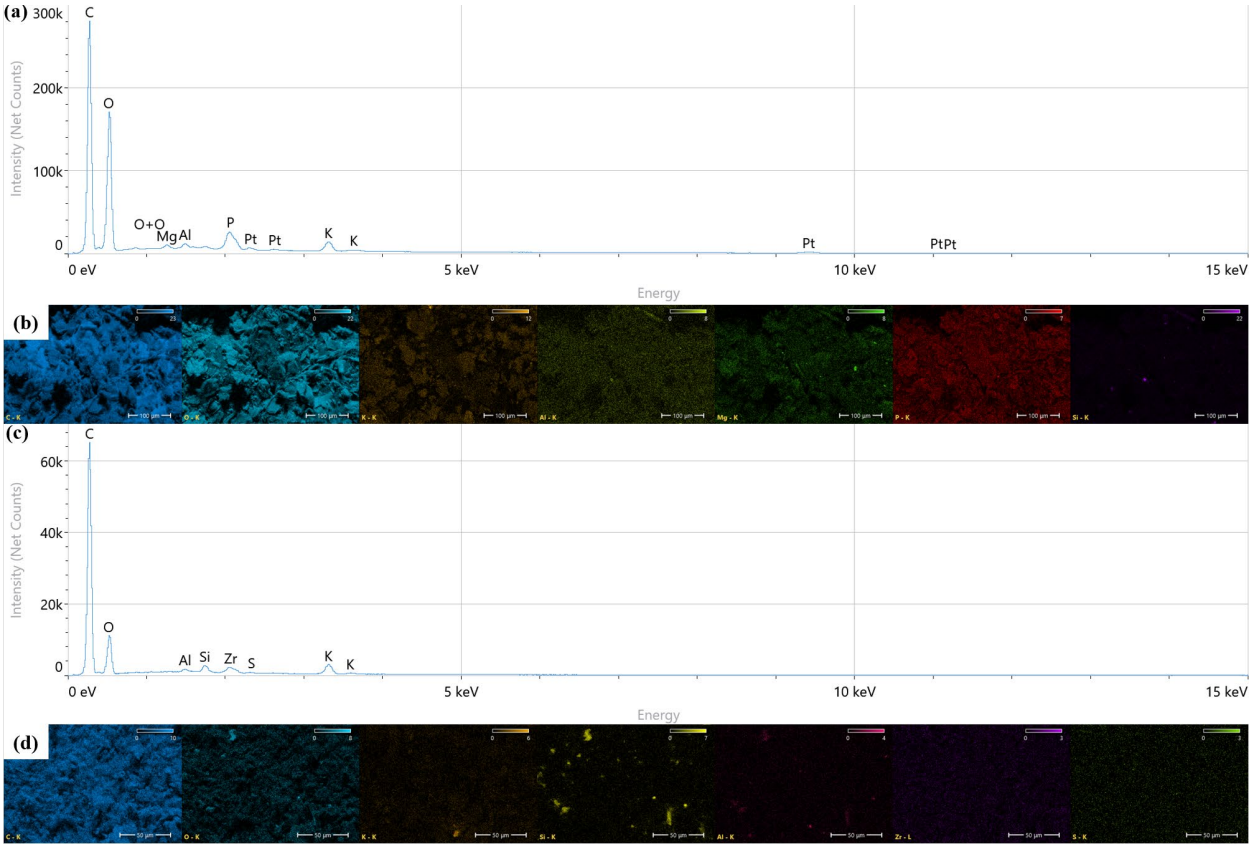


Figure 5. Energy-dispersive X-ray spectroscopy and their corresponding elemental mapping of (a, b) ground durian shells, and (c, d) durian shell-derived activated carbon at 800 °C.

As illustrated in Figure 6, the N_2 adsorption–desorption isotherms of AC_700 and AC_800 showed type IV isotherms with H4-type hysteresis loops, demonstrating the formation of mesoporous structures with a predominant pore-size distribution in the range of 2–3 nm. In addition, increasing the treatment temperature substantially improved the specific surface area of activated carbon materials, increasing from 499.44m^2 g^{-1} (AC_700) to 737.03m^2 g^{-1} for AC_800. The higher BET surface area of AC_800 is attributed to its well-developed porous architecture and abundant defect sites generated during high-temperature pyrolysis, providing greater accessible surface area and enhanced interfacial interactions with reactant species.

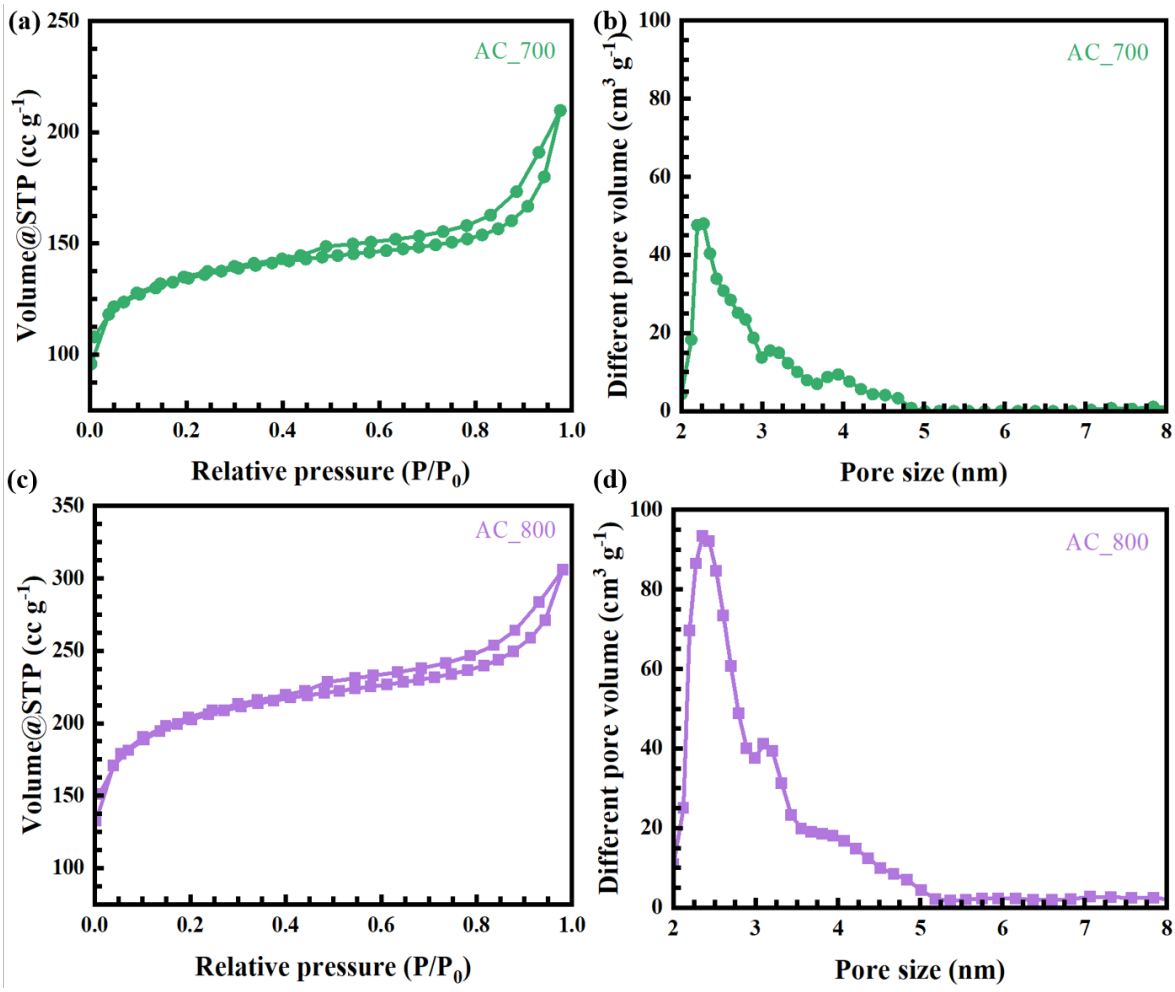


Figure 6. Nitrogen adsorption-desorption isotherm curves and their corresponding pore size distribution of (a, b) AC_700 and (c, d) AC_800 materials.

4. Conclusion

In summary, activated carbon materials are successfully derived from durian shell biomass via a combined hydrothermal carbonization and pyrolysis strategy. The role of treatment temperature on the resulting characteristics of durian shell-derived activated carbon materials is systematically investigated using various analytical techniques. Experimental results demonstrate the important role of calcination temperature in governing the structural and morphological evolution of the activated carbon materials. Among the investigated samples, the activated carbon produced at 800°C shows the largest surface area (737.03m^2 g^{-1}) with a mesoporous structure, highlighting its potential for diverse applications, including photocatalysis and electrocatalysis. In future work, the surface functional groups, electronic structures, and electrocatalytic characteristics of durian shell-derived activated carbon materials will be investigated in depth for various electrochemical reactions.

Declaration of competing interests

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] N.C. Thanh, A. Natarajan, C.T. Nguyen. (2026). "Durian fruit waste as future biomass for biohydrogen production in Southeast Asian countries". *International Journal of Hydrogen Energy*, 199 152867. DOI: https://doi.org/10.1016/j.ijhydene.2025.152867

[2] A. Choodum, W. Wongniramaikul, B. Kleangklao, C. Boonkanon, C. Phawachalotorn. (2026). "Resource-efficient conversion of durian shell waste into a magnetically recoverable adsorbent for methylene blue removal: Multi-response optimization, mechanistic insights, and practical wastewater treatment". *Environmental Technology & Innovation*, 44 105209. DOI: https://doi.org/10.1016/j.eti.2026.105209

[3] N.T. Ngan, N.M. Chau, N.T.M. Hanh. (2026). "Recycling Durian rind waste in the food processing industry: Phytochemical properties and food applications". *Journal of Science and Development Economics*, (2026) 44–54. DOI: https://doi.org/10.64632/jsde.eng.4.2026.967

[4] K.T. Dang, T.P. Ly, T. Danh, T.M.T. Ho, T.M.H. Chau, T.P. Le, H.V.T. Luong. (2026). "Circular valorization of durian husk into regenerable porous alginate–activated carbon beads for ammonium remediation in aquaculture wastewater". *Bioresource Technology Reports*, 36 103021. DOI: https://doi.org/10.1016/j.biteb.2026.103021

[5] T.B. Ly, C.D. Pham, K.D.D. Bui, D.A.K. Nguyen, L.H. Le, P.K. Le. (2024). "Conversion strategies for durian agroindustry waste: value-added products and emerging opportunities". *Journal of Material Cycles and Waste Management*, 26 1245–1263. DOI: https://doi.org/10.1007/s10163-024-01928-4

[6] W.W. Wai, A.F.M. Alkarkhi, A.M. Easa. (2010). "Effect of extraction conditions on yield and degree of esterification of durian rind pectin: An experimental design". *Food and Bioproducts Processing*, 88 209–214. DOI: https://doi.org/10.1016/j.fbp.2010.01.010

[7] K. Wangkawong, S. Paenchan, A. Thepyos, T. Jamnongkan, D. Channei, B. Inceesungvorn. (2024). "Sustainable carbonaceous material from durian peel to modify the photocatalytic activity of Ag/activated carbon/$BiVO_4$ for RhB degradation under visible light irradiation". *Inorganic Chemistry Communications*, 169 113023. DOI: https://doi.org/10.1016/j.inoche.2024.113023

[8] X. He, S. Ma, P. Ma, R. Cao, X. Tian, Y. Lu, J. Li, Y. Liang, Z. Wang, X. Lu. (2025). "Waste biomass durian shell carbon to derive N-rich porous microbial fuel cell anode for simultaneous dye degradation and electricity generation". *Bioresource Technology*, 436 132984. DOI: https://doi.org/10.1016/j.biortech.2025.132984

[9] M.T. Pham, T.K.Y. Truong, T.K.T. Truong, T.P. Le, T.B.Q. Tran, H.V.T. Luong. (2025). "Activated carbon synthesis from durian peel for ammonium ion adsorption". *CTU Journal of Innovation and Sustainable Development*, 17 91–100. DOI: https://doi.org/10.22144/ctujoisd.2025.038

[10] D.B. Ninh, M.D. Vu, V.A. Hoang, D.L. Vu, C.S. Kim, I.H. Nurwahid. (2025). "Activated carbon-derived from durian peels for the adsorption of methylene blue dye". *Journal of Dispersion Science and Technology*, 1–12. DOI: https://doi.org/10.1080/01932691.2025.2527267

[11] R.A.J. Gamay, P.M.N. Botecario, P.D.C. Sanchez, M.C. Alvarado. (2024). "Durian (Durio zibenthinus) waste: a promising resource for food and diverse applications-a comprehensive review". *Food Production, Processing and Nutrition*, 6 27. DOI: https://doi.org/10.1186/s43014-023-00206-4

[12] P. Numee, T. Sangtawesin, A.H. Ma'Radzi, K. Kanjana. (2025). "Green synthesis of durian shell-derived activated carbon with enhanced carboxylic functionalization and graphitization via gamma irradiation in ethanol and ethylene glycol for supercapacitor applications". *Biomass and Bioenergy*, 199 107945. DOI: https://doi.org/10.1016/j.biombioe.2025.107945

[13] S. Chitpreecha, U.S. Veerasamy, K. Punyawudho, C. Chaichana, C. Sekine, Y. Mona. (2026). "Effect of chemical activation agents on properties of durian peel-derived activated carbon for high-energy supercapacitor applications". *Biomass and Bioenergy*, 210 109031. DOI: https://doi.org/10.1016/j.biombioe.2026.109031

[14] M.K. Nayak, B.B. Sahoo, D.N. Thatoi, S. Nazari, R. Ali, A.J. Chamkha. (2024). "Recent advances on supercapacitor electrode materials from biowastes-a review". *Journal of Science: Advanced Materials and Devices*, 9 100734. DOI: https://doi.org/10.1016/j.jsamd.2024.100734

[15] C.D. Sulistiyo, K.-C. Cheng, H.J. Su'andi, M. Yuliana, C.-W. Hsieh, S. Ismadji, A.E. Angkawijaya, A.W. Go, H.Y. Hsu, P.L. Tran-Nguyen, S.P. Santoso. (2022). "Removal of hexavalent chromium using durian in the form of rind, cellulose, and activated carbon: Comparison on adsorption performance and economic evaluation". *Journal of Cleaner Production*, 380 135010. DOI: https://doi.org/10.1016/j.jclepro.2022.135010

[16] S. Tan, R. Wang, J. Dong, W. Yang, K. Guo, Z. Zhao, Q. Yin, L. Ge. (2027). "Unlocking buried active sites in Fe–N–C catalysts through hierarchical open mesoporous nanostructures for efficient oxygen reduction reaction". *Applied Catalysis B: Environment and Energy*, 401 127296. DOI: https://doi.org/10.1016/j.apcatb.2026.127296

[17] D. Zhang, Y. Zhang, H. Liu, Y. Xu, J. Wu, P. Li. (2023). "Effect of pyrolysis temperature on carbon materials derived from reed residue waste biomass for use in supercapacitor electrodes". *Journal of Physics and Chemistry of Solids*, 178 111318. DOI: https://doi.org/10.1016/j.jpcs.2023.111318

[18] F. Shen, S. Yao, Y. Pei, R. Sun. (2025). "Sustainable waste Biomass-Derived porous carbons with superior hierarchical porosity for High-Performance CO_2 capture". *Journal of Porous Materials*, 32 2413–2425. DOI: https://doi.org/10.1007/s10934-025-01859-x