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RED ONION PEEL BIOMASS CARBON MICROPARTICLES FOR AMMONIA ADSORPTION FOR SUPPORTING HYDROGEN STORAGE AND SUSTAINABLE DEVELOPMENT GOALS (SDGS) WITH ISOTHERM ANALYSIS

ASEP BAYU DANI NANDIYANTO[1,*], NABILA RAYA PUTRI[1],
NADYA NOOR FIRDAUS[1], NAILLA DITTA ANZETY[1],
SITI HERYANI AL'HAFSAH[1], SYERIL AMOUZA YUNATRAYA[1],
MELI FIANDINI[1], MUHAMMAD ROIL BILAD[2], TEGUH KURNIAWAN[3],
INDRA M. GANDIDI[1], YUSEP SUKRAWAN[1]

[1]Universitas Pendidikan Indonesia, Bandung, Indonesia
[2]Universiti Brunei Darussalam, Brunei Darussalam
[3]Universitas Sultan Ageng Tirtayasa, Serang, Indonesia
[*]Corresponding Author: nandiyanto@upi.edu

Abstract

This study investigated the potential of red onion peel biomass carbon microparticles as a sustainable material for ammonia adsorption, with applications in hydrogen storage. Red onion peels, commonly regarded as agricultural waste, were processed into adsorbents through drying, roasting at 200 °C, grinding, and sieving into various particle sizes (i.e. 63, 75, and 105 µm). Isotherm analysis indicated that the Langmuir model best described the adsorption process, with smaller particle sizes exhibiting enhanced efficiency due to increased surface area. The Freundlich, Temkin, and Dubinin-Radushkevich models further supported the adsorption behaviour, confirming physical adsorption mechanisms. This research emphasizes the dual benefits of utilizing agricultural waste for environmental applications and contributing to hydrogen storage technologies. The findings position red onion peel biomass as a cost-effective and eco-friendly material, aligning with circular economy principles and offering innovative solutions for sustainable ammonia management and hydrogen-based energy systems. This study also supports current issues in sustainable development goals (SDGs).

Keywords: Ammonia adsorption, Carbon microparticles, Hydrogen storage, Red onion peel biomass, Sustainable waste management.

1. Introduction

Ammonia (NH_3) is emerging as a promising carrier for hydrogen storage due to its high hydrogen content, low liquefaction pressure, and well-established production and distribution infrastructure [1]. With a hydrogen content of approximately 17.6% by weight, ammonia offers a viable solution for large-scale energy storage and transportation. However, ammonia is highly corrosive and toxic, posing significant challenges in handling, storage, and utilization. To address these issues, efficient adsorption technologies are required to capture and stabilize ammonia, ensuring safe handling while maintaining its potential as a hydrogen carrier.

One of the excellent adsorbents is biomass [2]. Previous studies regarding the use of biomass for the adsorption process are shown in Table 1. This table highlights the effectiveness of various biomass-derived materials in wastewater treatment, particularly for ammonia adsorption. Studies demonstrate that agricultural and industrial wastes, such as banana peel, rice husk, coffee husk, coconut shell, bagasse, seaweed, hevea brasilies, pineapple peel, cocoa shells, and pine sawdust can be converted into carbon or similar adsorbents with high adsorption efficiency. These materials are cost-effective and sustainable, offering viable alternatives to conventional adsorbents. The performance of these adsorbents depends on factors such as preparation methods (e.g.; pyrolysis and chemical activation), surface area, pore structure, and functional groups. For instance, banana peel at high temperatures achieved significant reductions in ammonia and COD, while multi-stage activation of salak skin increased pore volume and porosity. Chemical activators like H_3PO_4 and KOH enhance adsorption capabilities by optimizing the material's physicochemical properties. Isotherm models, such as Langmuir and Freundlich, are commonly used to analyse adsorption behaviour, helping to identify optimal conditions for maximum efficiency. In addition to ammonia removal, some materials also reduce other pollutants, such as COD and BOD, in diverse wastewater types, including tofu factory effluents and aquaculture media. These papers underscored the potential of biomass-derived adsorbents for ammonia adsorption, promoting sustainable waste management and environmental protection.

Table 1. Previous research on adsorbent materials derived from biomass for adsorption of pollutants and their results and weaknesses.

No.	Raw materials	Adsorbent	Results and weakness	Ref.
1	Banana peel	Biochar	The degradation efficiency of Methylene Blue reached 93.3% for a concentration of 80 mg/L at pH 2 for 90 minutes and using a biochar catalyst with a concentration of 15 mg/L and 0.2 mL/L H_2O_2. At a higher concentration of Methylene Blue (> 80 mg/L) it will decrease slightly more because the number of hydroxyl radicals produced will not be enough to overhaul all the molecules.	[3]

No.	Raw materials	Adsorbent	Results and weakness	Ref.
2	Rice Husk	KOH-RH, KOH-RHH, and AgNP-KOH-RH	The modified adsorbents, especially KOH-RHH and AgNP-KOH-RH, exhibit high adsorption capacity, efficient colour removal, and good regeneration ability, making them effective and environmentally friendly alternatives for industrial wastewater treatment. Raw adsorbents take longer to reach their maximum adsorption capacity compared to modified adsorbents.	[4]
3	Coffee husk	Activated carbon carbonaceous hydrochar	The adsorption capacity of methylene blue shows optimal results based on the Langmuir isotherm model. There has been no in-depth study regarding the costs on a large scale and the decrease in efficiency at high dye concentrations.	[5]
4	Coconut shell	Activated carbon	Efficiency for removing Cr(VI) is achieved by reaching 94% with pH 2 at a maximum adsorption capacity of 26 mg/g. The decrease in adsorption capacity and high concentration is due to the adsorbent surface becoming saturated at the time of site activity.	[6]
5	Bagasse	Activated carbon	The highest boron adsorption efficiency which is 75% occurs at a temperature of 25 °C with a contact time of 2 hours. Reduced adsorption efficiency at high temperatures of >35 °C or low temperatures of <15 °C to limit its use in diverse environmental conditions.	[7]
7	Hevea brasilienss	Activated carbon	Best activated carbon obtained using KOH as an activator, with good adsorption properties (iodine, methylene blue, and benzene). Adsorption analysis is less valuable than other raw materials; and requires more precise activation methods, particularly temperature.	[9]
8	Pineapple peel	Activated carbon	The adsorption of Fe(III) reached its highest value of 55.26% with the use of 4 g of adsorbent, along with an increase in adsorbent porosity after treatment. Adsorbents require an activation process, and their efficiency tends to be lower if the contact time is insufficient.	[10]
9	Cocoa shells	Natural adsorbent	The adsorption isotherm pattern that occurs in Cocoa shell adsorbent follows an isotherm Langmuir and Freundlich isotherms but tends to follow the Langmuir isotherm. Need activation of cocoa pod husk adsorbent was carried out using another activator solution other than HNO_3 solution,	[11]
10	Pine sawdust	Biochar	PSB-700 has the highest adsorption capacity (6.09 mg/g) compared to PSB-5 00 (4.78 mg/g) and PS (3.47 mg/g). In addition, Effective on neutral pH and alkaline. The adsorption efficiency decreases when the cadmium concentration is high, and the desorption is significant in the acidic state.	[12]

The reviewed studies in Table 1 demonstrate the potential use of biomass for adsorbent [13], and the efficacy of various biomass-derived materials, such as cassava skins, banana peels, coconut shells, and others, in ammonia adsorption. However, none of these studies specifically address the use of red onion peel biomass, despite its abundance and potential as a low-cost, eco-friendly material. Additionally, while ammonia adsorption is a central focus, the integration of ammonia adsorption into hydrogen storage applications remains unexplored, leaving a critical research gap in leveraging ammonia as a hydrogen carrier. Most studies emphasize the removal of ammonia from wastewater or other environments but do not delve into the particle characterization or isotherm modelling necessary for optimizing the adsorbent's performance for advanced applications, such as hydrogen storage. Furthermore, the role of microparticle size, surface area, and functional group chemistry in influencing adsorption efficiency remains underexplored for red onion peel-based adsorbents.

In our previous studies, we reported a method for producing carbon biochar from various raw materials: banana stem [14], pumpkin seeds [15], eggshell waste [16, 17], natural zeolite [18], rice husk [19], tamarind [20], date palm seeds [21], mangosteen [22], water hyacinth [23], olive industry solid waste [24], and others**.** These materials were primarily utilized as adsorbents in various environmental applications, focusing on wastewater treatment, dye removal, and pollution control. Many of them were derived from agricultural, food, and industrial waste, highlighting the studies' emphasis on sustainability and waste utilization. This body of work contributes significantly to advancing sustainable technologies for environmental protection, promoting the use of agricultural and industrial waste for adsorption, and improving understanding of adsorption mechanisms through experimental and computational approaches. The research is valuable for academic, industrial, and educational contexts, driving innovation in wastewater treatment, pollution control, and sustainable material development.

This study aims to bridge these gaps by focusing on red onion peel biomass carbon microparticles, investigating their adsorption properties for ammonia removal, and evaluating their potential to support hydrogen storage. Through detailed isotherm analysis and particle characterization, this research provides novel insights into the dual role of red onion peel biomass in environmental remediation and renewable energy systems.

In general, red onion peel, often discarded as agricultural waste, is rich in lignocellulosic compounds such as cellulose, hemicellulose, and lignin. These compounds contain functional groups like hydroxyl (-OH) and carbonyl (C=O), which contribute to their high adsorption potential for pollutants such as ammonia. Through pyrolysis, red onion peel can be converted into biomass-derived carbon microparticles with highly porous structures and active surface groups. These properties facilitate strong interactions with ammonia molecules through Van der Waals forces, hydrogen bonding, and ionic attraction, enhancing its adsorption capabilities. Such characteristics make red onion peel a viable material for ammonia adsorption, particularly for applications in hydrogen storage and environmental remediation. Adsorption technology has emerged as a widely recognized solution for ammonia management due to its simplicity, efficiency, and adaptability. Low-cost, renewable adsorbents derived from biomass, such as red onion peel, offer eco-friendly alternatives to conventional materials. Their adsorption behaviour is influenced by physicochemical properties, including surface area, pore structure, and functional groups. Particle size and preparation methods, such as chemical activation, play a crucial role in optimizing performance, as observed in studies on sugarcane bagasse and coffee grounds.

Isotherm models are often employed to analyse adsorption mechanisms. The Langmuir model assumes monolayer adsorption on homogeneous surfaces, while the Freundlich model accounts for multilayer adsorption on heterogeneous surfaces. Additional models, such as Temkin and Dubinin-Radushkevich, provide insights into thermodynamic and kinetic aspects, elucidating adsorption energy and mechanisms.

By examining adsorption performance under varying pyrolysis conditions, particle sizes, and surface functionalization, this research provides a comprehensive evaluation of red onion peel's capacity as a sustainable adsorbent. Isotherm analysis using models such as Langmuir, Freundlich, and Dubinin-Radushkevich offers critical insights into the adsorption mechanisms and optimal operating conditions.

The findings contribute to resource recovery and environmental sustainability by transforming agricultural waste into high-performance adsorbents. This research aligns with global efforts to promote the circular economy and address water pollution challenges, highlighting red onion peel's potential as a cost-effective and eco-friendly solution for ammonia management and hydrogen storage in renewable energy systems. This study also supports the current issue of sustainable development goals (SDGs), as reported elsewhere [25-29].

2. Method

Red onion peel biomass, sourced from abundant kitchen waste, was cleaned thoroughly with water to remove any adhered dirt. The cleaned samples were sun-dried until most of the moisture was removed. Subsequently, the dried samples were subjected to oven-drying at 170 °C for 4 hours to ensure complete dehydration. The biomass was then crushed into smaller fragments and sieved using mesh sizes of 500, 250, and 100 µm (Earth Foundation Publishing Nusantara, Indonesia). The dried red onion peels were further put into the reactor by heating at 250 °C to induce pyrolysis and form carbon with enhanced porosity and structural integrity. To improve adsorption performance, the carbon was chemically enriched with amides, known to increase its affinity for specific pollutants. The carbon particles were then put into the adsorption process, following our previous studies [30-32].

A stock solution of ammonia (100 ppm) was prepared by dissolving 1 g of NH_4Cl in 1 L of distilled water. This stock solution was diluted to produce working solutions with concentrations of 10, 20, 40, 60, and 80 ppm. The NH_4^+ ion concentrations were analysed using the colorimetric method with a Hanna HI733 colorimeter. The adsorption studies were conducted using red onion peel-carbon of particle sizes 500 µm, 250 µm, and 100 µm. A mass of 0.05 g of the adsorbent was added to 50 mL of ammonium solutions of varying concentrations. The experiments were performed under constant temperature and pressure. Adsorption kinetics were studied by monitoring ammonium concentrations at time intervals of 10 minutes over 2 hours. Isotherm analysis was conducted for the same duration, using ammonium solutions of different concentrations.

The red onion peel-based carbon was characterized for its morphology using a Digital Microscope (BXAW-AX-BC, China). The adsorption efficiency and quality of the carbon were assessed using Hanna Instrument reagents. This methodology ensured a thorough evaluation of the red onion peel biomass carbon microparticles' adsorption capacity, highlighting their potential for ammonia removal and hydrogen storage applications.

3.Method

Figures 1(a)-1(c) illustrate the surface morphology of red onion peel-based adsorbent particles across three particle sizes: 500, 250, and 100 μm. It is evident from the images that the 100 μm particles (Fig. 1(c)) were significantly smaller compared to the 500 (Fig. 1(a)) and 250 μm (Fig. 1(b)) particles. Despite the differences in size, all three particle groups exhibit irregular shapes and heterogeneous surface structures, which are beneficial for adsorption processes. These results also confirmed that pyrolysis is effective in converting biomass into carbon [33-37].

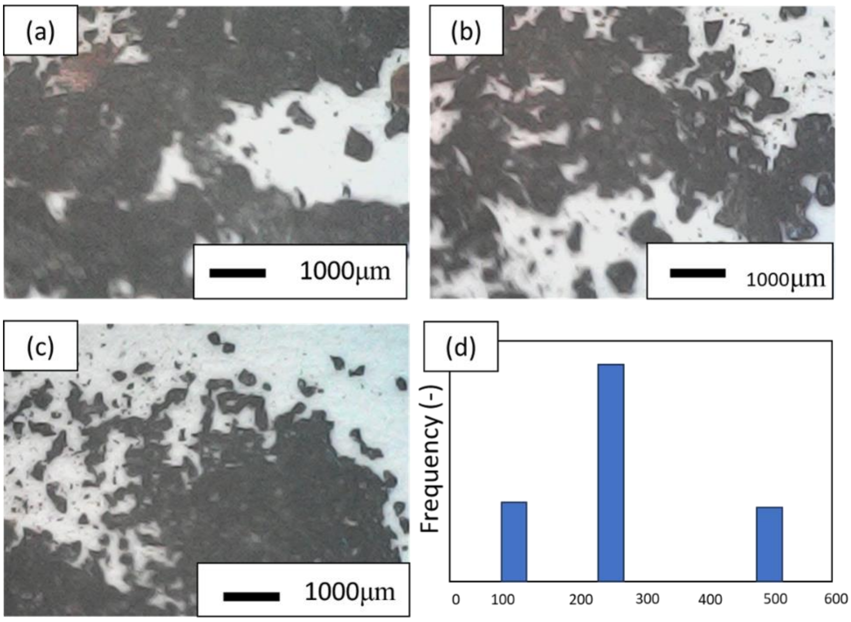

Fig. 1. Digital microscope camera images of red onion peel-based adsorbents, illustrating particle size distributions: (a) 125, (b) 250, and (c) 500 μm, accompanied by (d) a chart analysis.

Table 2 represents the adsorption mechanism of ammonia using red onion peel adsorbents, showcasing a combination of physical (physisorption) and chemical (chemisorption) interactions. The table summarizes the performance of red onion peel-based adsorbents for ammonia adsorption across three particle sizes (500, 250, and 100 μm) based on ten isotherm models. The Langmuir model, which assumes monolayer adsorption, demonstrated high correlation coefficients ($R^2 > 0.70$) for all sizes, confirming the suitability of this model. Smaller particles exhibited higher adsorption efficiency, as evidenced by their higher Langmuir constants (K_L) and favourable R_L values ($0 < R_L < 1$). The Freundlich model indicated multilayer adsorption with strong R^2 values for 500 and 250 μm, and an adsorption intensity

(n_F) close to 1, suggesting linear adsorption. Temkin's model supported physical adsorption (β_T < 8 kJ/mol), particularly for the larger particle sizes. The Dubinin-Radushkevich model identified both physical (E < 8 kJ/mol) and chemical adsorption (E > 8 kJ/mol), varying with particle size. Other models, such as Halsey and Jovanovic, highlighted distinct adsorption mechanisms, with smaller particles demonstrating higher capacity due to their increased surface area. Models like Flory-Huggins and Fowler-Guggenheim showed lower R^2 values, suggesting limited applicability. Overall, smaller particles (100 μm) displayed enhanced adsorption performance due to their larger surface area and pore accessibility, making them highly effective for ammonia adsorption.

Table 2. Analysis results from various adsorption isotherm models.

Model	**Parameter**	**Particle Size (μm)**			**Note**
		500	**250**	**100**	
Langmuir	R^2	1	1	0.927	Monolayer (R^2 > 0.70)
	Qmax	1.443	1.443	0.390	Maximum adsorption capacity (mg/g)
	R_L	0.314	0.448	0.298	Favourable adsorption (0 < R_L < 1)
	K_L	0.693	0.693	2.721	Langmuir constant
Freundlich	R^2	1	1	0.819	Multilayer (R^2 > 0.70)
	Kf	2.718	2.718	2.568	Freundlich constant
	nF	1	1	1.060	*n* > 1: physical bonds indicating cooperative adsorption *n* = 1: linear adsorption
	1/ n	1	1	0.943	1/*n* > 1: Favourable adsorption due to cooperative interaction.
Temkin	R^2	0.947	0.945	0.678	R^2 > 0.70: monolayer
	A_T (L/g)	0.219	-1.345	29.019	Binding energy coefficient
	β_T (J/mol)	4.480	2.488	0.632	Physical adsorption (β_T < 8).
Dubinin-Raduskhevich	R^2	0.924	0.896	0.942	Micropore (R^2 > 0.70)
	E (kJ/mol)	8.778	15.736	8.132	Physical adsorption (E < 8 kJ/mol). Chemical adsorption (E > 8 kJ/mol).
Jovanovic	R^2	0.948	0.946	0.586	Monolayer

Model	Parameter	Particle Size (μm)			Note
		500	250	100	
					(R^2 > 0.70) multilayer (R^2 < 0.70)
	$Qmax$	3.759	2.999	15.657	Maximum adsorption capacity (mg/g).
	K_J	0.353	0.196	0.188	Jovanovic constant
Halsey	R^2	1	1	0.819	Multilayer (R^2 > 0.70)
	n_H	1	1	1.060	Halsey constant
	K_H	2	2	13.028	Halsey constant
Harkin-Jura	R^2	0.895	0.865	0.622	Multilayer (R^2 > 0.70) Monolayer (R^2 < 0.70)
	AH	-3.742	-10.603	-79.096	Constant
	BH/AH	0.179	0.089	0.011	Constant
Flory-Huggins	R^2	0.586	0.362	0.040	R^2 < 0.70: Limited compatibility and monolayer
	nFH	1.214	0.508	0.077	n_{FH} < 1: Active adsorbent zone interaction
	kFH	5.667	0.822	0.184	Constant
	$\Delta G°$	41.676	-4.700	-40.635	Spontaneous ($\Delta G°$ < 0) non-spontaneous ($\Delta G°$ > 0).
Fowler Guggenhe	R^2	0.770	0.812	0.359	Multilayer (R^2 > 0.70) Monolayer (R^2 < 0.70)
	K_{FG}	8.829	8.111	0.001	Interaction between adsorbent and adsorbate
	W	-14.942	-11.573	-8.947	W < 0: Repulsive interactions between adsorbent molecules.
Hill-Deboer	R^2	0.539	0.934	0.732	Multilayer (R^2 > 0.70) Monolayer (R^2 < 0.70)
	k_1	9.329	1.987	5.265	Energy constant
	k_2	-6194	-2067	-3854	k_2 < 0: Endothermic with repulsion forces.

The study confirms the spontaneous nature of adsorption, as indicated by negative Gibbs free energy values, while pseudo-second-order kinetics suggest complex interactions between adsorbent and adsorbate. Smaller particle sizes demonstrated significantly higher adsorption capacities due to their larger surface area and increased availability of adsorption sites, highlighting the critical role of particle size in optimizing the adsorption performance. The correlation coefficient (R^2) values obtained from ammonia adsorption studies using biomass-derived carbon biochar, specifically red onion peel particles of varying sizes, indicate distinct isotherm model compatibility. The ranking of model applicability for each particle size is as follows:

(i) For 500 μm particles: Langmuir > Freundlich > Temkin > Dubinin-Radushkevich > Jovanovic > Halsey > Harkin-Jura > Flory-Huggins > Fowler-Guggenheim.

(ii) For 250 μm particles: Langmuir > Freundlich > Temkin > Dubinin-Radushkevich > Jovanovic > Halsey > Harkin-Jura > Flory-Huggins > Fowler-Guggenheim.

(iii) For 100 μm particles: Langmuir > Freundlich > Jovanovic > Halsey > Temkin > Dubinin-Radushkevich > Harkin-Jura > Fowler-Guggenheim > Flory-Huggins.

The adsorption phenomenon observed across the three particle sizes suggests a predominant monolayer adsorption mechanism, as described by the Langmuir model, with lateral interactions between the adsorbent and adsorbate (refer to Fig. 2). However, the results also indicate contributions from multilayer adsorption mechanisms, particularly for larger particles, due to pore filling and the heterogeneous distribution of pore structures.

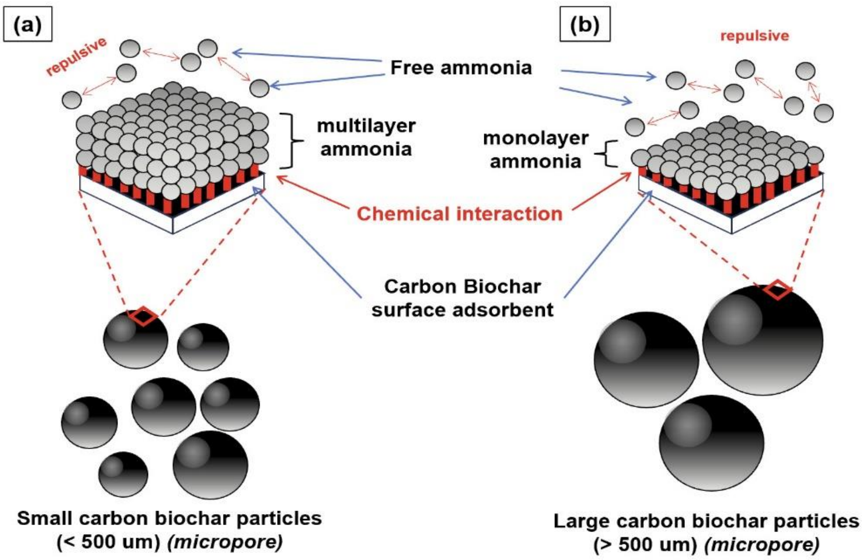

Fig. 2. Ammonia adsorption mechanism, where a combination of physical (physisorption) and chemical (chemisorption) interactions occurs.

Pseudo-second-order kinetic analysis supports the cooperative nature of these interactions. Although chemisorption bonds were weak, the negative Gibbs free energy values indicate that the adsorption process is spontaneous. The results also highlight the critical influence of particle size on adsorption capacity. Smaller particles (e.g., 100 μm) offer a significantly larger surface area, increasing the number of active adsorption sites and enhancing the efficiency of ammonia capture. This makes biomass carbon biochar from red onion peel highly effective for ammonia adsorption, supporting its potential application in hydrogen storage systems where ammonia serves as a hydrogen carrier.

In addition, despite promising results, this study has some limitations. The adsorption experiments were conducted under controlled laboratory conditions, which may not fully represent real-world scenarios. The effect of competing ions and contaminants commonly found in wastewater was not explored, which could influence adsorption efficiency. Additionally, the long-term stability and reusability of the banana peel adsorbents were not investigated, which is critical for practical applications.

Future research should focus on the following areas:

- Further analysis: Analysis of material for understanding surface area (by nitrogen sorption) and morphology (using electron microscope)
- Real-world applications: Testing the adsorbents in complex wastewater systems with multiple contaminants to assess their practical efficiency.
- Adsorbent modification: Investigating chemical or physical modifications of banana peel-based adsorbents to enhance adsorption capacity and selectivity for ammonia.
- Reusability and stability: Evaluating the durability and regeneration potential of the adsorbents over multiple cycles to determine their economic viability.
- Integration into hydrogen storage systems: Exploring methods to recover ammonia efficiently and convert it into hydrogen for clean energy applications.
- Scale-up studies: Developing scalable production methods for banana peel adsorbents to facilitate industrial applications.

By addressing these limitations and exploring the suggested future directions, banana peel-based adsorbents can be further optimized to play a pivotal role in environmental remediation and sustainable energy solutions. Finally, this study adds new information and ideas regarding the use of carbon for the adsorption process, as reported elsewhere [38-42]. This study also supports the current issue of SDGs from using biomass and the potential use of biomass for supporting clean energy.

4. Conclusion

This study has demonstrated that red onion peel biomass, often regarded as agricultural waste, is an effective and eco-friendly material for ammonia adsorption. Isotherm analysis revealed that the Langmuir model, which describes monolayer adsorption on a homogeneous surface, provided the best fit for the experimental data. This confirms the material's high specificity and adsorption capacity for ammonia, making it suitable for environmental remediation applications. The research also highlighted the critical influence of physicochemical properties, such as particle size, surface morphology, and pore structure, on adsorption performance. Smaller particles exhibited higher adsorption capacities due to their larger surface area, which increased the number of active sites for ammonia interaction. The dual contribution of physical and chemical adsorption mechanisms further enhanced the material's efficiency in pollutant removal. Beyond its application in wastewater treatment, this study introduces red onion peel biomass carbon as a promising material for hydrogen storage systems. Ammonia, being a viable hydrogen carrier due to its high hydrogen content and established infrastructure, requires efficient and safe handling materials. Red onion peel biochar's ability to effectively adsorb and stabilize ammonia offers a sustainable and cost-effective solution for hydrogen storage. By transforming an abundant and low-cost waste product into a high-performance adsorbent, this research addresses environmental sustainability challenges while contributing to the advancement of renewable energy storage technologies.

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References

1. Negro, V.; Noussan, M.; and Chiaramonti, D. (2023). The potential role of ammonia for hydrogen storage and transport: A critical review of challenges and opportunities. *Energies*, 16(17), 6192.
2. Li, S.; Yuan, X.; Deng, S.; Zhao, L.; and Lee, K.B. (2021). Tinjauan tentang penyerapan CO_2 yang berasal dari biomassa: penyerap, penyerap, penyerapan, dan saran. *Tinjauan Energi Terbarukan dan Berkelanjutan*, 152, 111708.
3. Ngankam, E.S.; Dai-Yang, L.; Debina, B.; Baçaoui, A.; Yaacoubi, A.; and Rahman, A.N. (2020). Preparation and characterization of magnetic banana peel biochar for Fenton degradation of methylene blue. *Materials Sciences and Applications*, 11(06), 382.
4. Hossain, N.; Nizamuddin, S.; and Shah, K. (2022). Thermal-chemical modified rice husk-based porous adsorbents for Cu (II), Pb (II), Zn (II), Mn (II) and Fe (III) adsorption. *Journal of Water Process Engineering*, 46, 102620.
5. Tran, T.H.; Le, A.H.; Pham, T.H.; Nguyen, D.T.; Chang, S.W.; Chung, W.J.; and Nguyen, D.D. (2020). Adsorption isotherms and kinetic modeling of methylene blue dye onto a carbonaceous hydrochar adsorbent derived from coffee husk waste. *Science of the Total Environment*, 725, 138325.
6. Chandana, L.; Krushnamurty, K.; Suryakala, D.; and Subrahmanyam, C. (2020). Low-cost adsorbent derived from the coconut shell for the removal of hexavalent chromium from aqueous medium. *Materials Today*: *Proceedings*, 26, 44-51.
7. Liao, L.; Chen, H.; He, C.; Dodbiba, G.; and Fujita, T. (2024). Boron Removal in Aqueous Solutions Using Adsorption with Sugarcane Bagasse Biochar and Ammonia Nanobubbles. *Materials*, 17(19), 4895.
8. Kusuma, I.D.G.D.P.; Wiratini, N.M.; and Wiratma, I.G.L. (2017). Isoterm adsorpsi Cu^{2+} oleh biomassa rumput laut Eucheuma spinosum. *Jurnal Pendidikan Kimia Undiksha*, 1(1).
9. Novitasari, D.; and Lamuru, A.S. (2024). Pembuatan karbon aktif dari cangkang buah karet melalui karbonasi suhu 600 ℃ dengan aktivator KOH. *Jurnal Crystal*: *Publikasi Penelitian Kimia dan Terapannya*, 6(1), 35-44.

10. Abd Ghapar, N.F.; Abu Samah, R.; and Abd Rahman, S. (2020). Pineapple peel waste adsorbent for adsorption of Fe(III). *IOP Conference Series: Materials Science and Engineering*, 991(1), 012093.
11. Purnamawati, H.; and Utami, B. (2014). Pemanfaatan limbah kulit buah kakao (Theobroma cocoa L.) sebagai adsorben zat warna rhodamin B. *Prosiding Seminar Nasional Fisika dan Pendidikan Fisika* (*SNFPF*) *Ke*-5 2014, 5(1), 12-18.
12. Liu, X.; Xu, X.; Dong, X.; and Park, J. (2019). Adsorption characteristics of cadmium ions from aqueous solution onto pine sawdust biomass and biochar. *BioResources*, 14(2), 4270-4283.
13. Permatasari, N.; Sucahya, T.N.; and Nandiyanto, A.B.D. (2016). Agricultural wastes as a source of silica material. *Indonesian Journal of Science and Technology*, 1(1), 82-106.
14. Nandiyanto, A.B.D.; Azizah, N.N.; and Rahmadianti, S. (2021). Isotherm study of banana stem waste adsorbents to reduce the concentration of textile dying waste. *Journal of Engineering Research*, 9, 16063.
15. Nandiyanto, A.B.D.; Hofifah, S.N.; Inayah, H.T.; Putri, S.R.; Apriliani, S.S.; Anggraeni, S.; Usdiyana, D.; and Rahmat, A. (2021). Adsorption isotherm of carbon microparticles prepared from pumpkin (Cucurbita maxima) seeds for dye removal. *Iraqi Journal of Science*, 62(5), 1404-1414.
16. Nandiyanto, A.B.D.; Nur, N.; and Taufik, R.S.R. (2022). Investigation of adsorption performance of calcium carbonate microparticles prepared from eggshells waste. *Journal of Engineering Science and Technology*, 17(3), 1934-1943.
17. Nandiyanto, A.B.D.; Ragadhita, R.; Girsang, G.C.S.; Anggraeni, S.; Putri, S. R.; Sadiyyah, F.H.; and Hibatulloh, M.R. (2022). Effect of palm fronds and rice husk composition ratio on the mechanical properties of composite-based brake pad. *Moroccan Journal of Chemistry*, 10(4), 10-4.
18. Nandiyanto, A.B.D.; Putri, S.R.; Anggraeni, S.; and Kurniwan, T. (2022). Isotherm adsorption of 3000-µm natural zeolite. *Journal of Engineering Science and Technology*, 17(4), 2447-2460.
19. Nandiyanto, A.B.D.; Nugraha, W.C.; Yustia, I.; Ragadhita, R.; Fiandini, M.; Saleh, M.; and Ningwulan, D.R. (2023). Rice husk for adsorbing dyes in wastewater: Literature review of agricultural waste adsorbent, preparation of Rice husk particles, particle size on adsorption characteristics with mechanism and adsorption isotherm. *Journal of Advanced Research in Applied Mechanics*, 106(1), 1-13.
20. Nandiyanto, A.B.D.; Fiandini, M.; Ragadhita, R.; Maulani, H.; Nurbaiti, M.; Al-Obaidi, A.S.M.; Junas, J.; and Bilad, M.R. (2023). Sustainable biochar carbon biosorbent based on tamarind (Tamarindusindica L) seed: Literature review, preparation, and adsorption isotherm. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 32(1), 210-226.
21. Nandiyanto, A.B.D.; Ragadhita, R.; Fiandini, M.; and Maryanti, R. (2023). Curcumin dye adsorption in aqueous solution by carbon-based date palm seed: Preparation, characterization, and isotherm adsorption. *Journal of Applied Research and Technology*, 21(5), 808-824.
22. Nandiyanto, A.B.D.; Fiandini, M.; Fadiah, D.A.; Muktakin, P.A.; Ragadhita, R.; Nugraha, W.C.; and Al Obaidi, A.S.M. (2023). Sustainable biochar carbon

microparticles based on mangosteen peel as biosorbent for dye removal: Theoretical review, modelling, and adsorption isotherm characteristics. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* 10(1), 41-58.

23. Nandiyanto, A.B.D.; Fiandini, M.; and Al Husaeni, D.N. (2024). Research trends from the Scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review. *ASEAN Journal of Science and Engineering*, 4(1), 33-48.
24. Salahat, A.; Hamed, O.; Deghles, A.; Azzaoui, K.; Qrareya, H.; Assali, M.; and Rhazi, L. (2023). Olive Industry solid waste-based biosorbent: synthesis and application in wastewater purification. *Polymers*, 15(4), 797.
25. Nurramadhani, A.; Riandi, R.; Permanasari, A.; and Suwarma, I.R. (2024). Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs). *Indonesian Journal of Science and Technology*, 9(2), 261-286.
26. Gemil, K.W.; Na'ila, D.S.; Ardila, N.Z.; and Sarahah, Z.U. (2024). The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs). *ASEAN Journal of Science and Engineering Education*, 4(2), 181-192.
27. Kerans, G.; Sanjaya, Y.; Liliasari, L.; Pamungkas, J.; and Ate, G.Y. (2024). Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs). *ASEAN Journal of Science and Engineering*, 4(3), 383-404.
28. Krishnan, A.; Al-Obaidi, A.S.M.; and Hao, L.C. (2024). Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs). *Indonesian Journal of Science and Technology,* 9(3), 623-656.
29. Djirong, A.; Jayadi, K.; Abduh, A.; Mutolib, A.; Mustofa, R.F.; and Rahmat, A. (2024). Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges. *Indonesian Journal of Science and Technology*, 9(3), 657-678.
30. Ragadhita, R.; and Nandiyanto, A.B.D. (2021). How to calculate adsorption isotherms of particles using two-parameter monolayer adsorption models and equations. *Indonesian Journal of Science and Technology*, 6(1), 205-234.
31. Nandiyanto, A.B.D.; Ragadhita, R.; and Aziz, M. (2023). How to calculate and measure solution concentration using UV-vis spectrum analysis: Supporting measurement in the chemical decomposition, photocatalysis, phytoremediation, and adsorption process. *Indonesian Journal of Science and Technology*, 8(2), 345-362.
32. Nandiyanto, A.B.D.; Fiandini, M.; Ragadhita, R.; and Aziz, M. (2023). How to purify and experiment with dye adsorption using carbon: Step-by-step procedure from carbon conversion from agricultural biomass to concentration measurement using UV Vis spectroscopy. *Indonesian Journal of Science and Technology*, 8(3), 363-380.

33. Jamilatun, S.; Aziz, M.; and Pitoyo, J. (2023). Multi-distributed activation energy model for pyrolysis of sugarcane bagasse: Modelling strategy and thermodynamic characterization. *Indonesian Journal of Science and Technology*, 8(3), 413-428.
34. Jelita, R.; Nata, I.F.; Irawan, C.; Jefriadi, J.; Anisa, M.N.; Mahdi, M.J.; and Putra, M.D. (2023). Potential alternative energy of hybrid coal from co-pyrolysis of lignite with palm empty fruit bunch and the kinetic study. *Indonesian Journal of Science and Technology*, 8(1), 97-112.
35. Mutolib, A.; Rahmat, A.; Triwisesa, E.; Hidayat, H.; Hariadi, H.; Kurniawan, K.; Sutiharni, S.; and Sukamto, S. (2023). Biochar from agricultural waste for soil amendment candidate under different pyrolysis temperatures. *Indonesian Journal of Science and Technology*, 8(2), 243-258.
36. Pebrianti, M.; and Salamah, F. (2021). Learning simple pyrolysis tools for turning plastic waste into fuel. *Indonesian Journal of Multidiciplinary Research*, 1(1), 99-102.
37. Sridevi, V.; Hamzah, H.T.; Jweeg, M.J.; Mohammed, M.N.; Al-Zahiwat, M.M.; Abdullah, T.A.; and Abdullah, O.I. (2024). Microwave pyrolysis of agricultural and plastic wastes for production of hybrid biochar: Applications for greener environment. *Indonesian Journal of Science and Technology*, 9(3), 791-820.
38. Anshar, A.M.; Taba, P.; and Raya, I. (2016). Kinetic and thermodynamics studies the adsorption of phenol on activated carbon from rice husk activated by $ZnCl_2$. *Indonesian Journal of Science and Technology*, 1(1), 47-60.
39. Khuluk, R.H.; and Rahmat, A. (2019). Removal of methylene blue by adsorption onto activated carbon from coconut shell (*Cocous nucifera L.*). *Indonesian Journal of Science and Technology*, 4(2), 229-240.
40. Dewi, R.; Shamsuddin, N.; Bakar, M.S.A.; Santos, J.H.; Bilad, M.R.; and Lim, L.H. (2021). Progress in emerging contaminants removal by adsorption/membrane filtration-based technologies: A review. *Indonesian Journal of Science and Technology*, 6(3), 577-618.
41. Rahal, Z.; Khechekhouche, A.; Barkat, A.; Sergeevna, S.A.; and Hamza, C. (2023). Adsorption of sodium in an aqueous solution in activated date pits. *Indonesian Journal of Science and Technology*, 8(3), 397-412.
42. Prihastuti, H.; and Kurniawan, T. (2022). Conversion of Indonesian coal fly ash into zeolites for ammonium adsorption. *ASEAN Journal for Science and Engineering in Materials*, 1(2), 75-84.