MARI

MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

Vol. 7 No. 2 (2026) 8-15
https://publisher.uthm.edu.my/periodicals/index.php/mari

Performance Evaluation of Activated Carbon Produced from Post-Consumer Paper for Wastewater Treatment

Auni Farahiyah Muhamad Waras[1], Nur Iman Safina Nazrul Izzad[1], Nur Nadia Natasya Khairul Ariffin[1], Norain Ahmad Nordin[1]*, Nuramirah Juma'at[1]

1 Department of Science and Mathematics, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Muar, Johor, MALAYSIA

*Corresponding Author: norainn@uthm.edu.my
DOI: https://doi.org/10.30880/mari.2026.07.02.002

Article Info

Received: 01 March 2026
Accepted: 01 May 2026
Available online: 30 June 2026

Keywords

Potassium hydroxide (KOH), zinc chloride ($ZnCl_2$), biochemical oxygen demand (BOD), turbidity, precursor

Abstract

Sustainably reusing waste materials offers promising solutions to environmental issues, particularly in the treatment of wastewater. In this study, the performance of activated carbon (AC) made from post-consumer paper in treating wastewater was evaluated using two chemical agents, potassium hydroxide (KOH) and zinc chloride ($ZnCl_2$), at varying concentrations. The AC was characterized by examining chemical modifications and surface functional groups using Fourier Transform Infrared Spectroscopy (FTIR). Treated wastewater was analyzed for biochemical oxygen demand (BOD), turbidity and pH levels to evaluate the efficiency of the activated carbon. The results showed that $ZnCl_2$ (1.0 M) achieved the lowest BOD (1.90 mg/L), turbidity (0.21 NTU), and near-neutral pH (7.6), while KOH (1.5 M) resulted in a BOD of 2.10 mg/L and the highest pH of 11.32. Among the two activating agents used, $ZnCl_2$ showed better performance in treating wastewater compared to KOH. These findings demonstrated the potential of wastepaper as a practical precursor for AC, which could support environmentally friendly water treatment methods and efficient waste disposal.

1. Introduction

Water pollution is a significant global problem that requires the development of environmentally friendly and cost-effective wastewater treatment systems. Effective wastewater treatment is essential for addressing these issues and achieving environmental sustainability [1]. Conventional treatment methods, such as coagulation-flocculation, sedimentation, and aeration, are commonly used. However, they often face limitations, including high operating costs and the generation of secondary waste [2]. Recently, AC has been used in various purification and adsorption processes, including water treatment. This highly porous, carbon-based material effectively adsorbs and retains organic compounds [3]. Nevertheless, commercially available activated carbons are costly due to the significant expenses associated with swelling, regeneration, and reactivation procedures [4]. Recent studies have focused on generating low-cost, high-efficiency activated carbon from high-carbon-content materials derived from agricultural, municipal, and industrial waste [5].

Agricultural residues and paper waste have been successfully converted into AC, demonstrating the potential of using materials derived from waste [6], [7]. However, there has been limited focus on post-consumer office paper, which is plentiful, high in cellulose, and frequently disposed of in landfills or incinerated. Converting wastepaper into AC not only helps reduce solid waste but also promotes practices aligned with a circular economy [8].

The efficacy of AC is significantly influenced by the activating agent employed. KOH generally produces micropores and elevated surface areas, whereas $ZnCl_2$ facilitates aromatization and mesoporous structure [7]. The identification of optimal conditions for wastewater treatment applications can be facilitated by comparing these two activators.

In Malaysia, rivers such as the Panchor River in Johor are facing increasing pollution from domestic and industrial discharges, often showing elevated BOD, high turbidity, and unstable pH levels [9]. Hence, the purpose of this study is to produce AC from post-consumer office paper using KOH and $ZnCl_2$ as activating agents. The resulting AC was characterized by examining surface functional groups through FTIR analysis. Additionally, its effectiveness in improving wastewater quality was evaluated by measuring BOD, turbidity, and pH levels. The findings are anticipated to demonstrate the potential of paper waste as a low-cost precursor for AC and contribute to sustainable solutions for water treatment.

2. Materials and Method

This section outlines the raw materials, preparation procedures and characterization techniques used to produce and evaluate the activated carbon.

2.1 Materials

Post-consumer paper was collected from two sources, office wastepaper from SK Paka 3 and medical-related wastepaper from Hospital Sultanah Aminah (HSA). The chemical activating agents used in this study were KOH and $ZnCl_2$, both obtained from the laboratory stock of Universiti Tun Hussein Onn Malaysia (UTHM). The wastewater used for the treatment experiment was collected from Sungai Panchor, located in Muar, Johor.

2.2 Preparation of Activated Carbon

The preparation of activated carbon began with the collection of post-consumer office paper, which was cut into small pieces and shredded. The shredded paper was then allowed to cool at room temperature after being heated for two hours at 90 °C in an oven to remove moisture content [8]. Then, the paper was allowed to cool at room temperature before proceeding to the chemical activation stage. 100 g of dried samples were soaked in 0.15 L of solutions of KOH and zinc chloride $ZnCl_2$ at concentrations of 0.5, 1.0, and 1.5 M for one hour. The soaked samples were then heated in a furnace at 600 °C for six hours [3]. Once cooled, the resulting carbon was dried, ground into a powder, and rinsed multiple times with distilled water to remove any residual chemicals.

2.3 Characterization of Activated Carbon

The prepared AC was analyzed using FTIR to identify the surface functional groups [10]. This technique detects specific molecular vibrations based on infrared light absorption, indicating the presence of functional groups such as hydroxyl (3200–3600 cm^{-1}), carbonyl (1600–1800 cm^{-1}) and carboxyl groups. These functional groups are essential in determining the adsorption capacity and chemical reactivity of AC.

2.4 Experimental Setup

For the wastewater treatment, the AC was added to the wastewater at a 1:1 ratio. The mixture was stirred for 90 minutes at room temperature using a magnetic stirrer plate and then filtered to remove larger particles. The treated water was analyzed for pH, turbidity, and BOD. FTIR confirmed the presence of surface functional groups, while BOD and turbidity served as indicators of treatment effectiveness [10], [11].

Fig. 1 illustrates the overall procedure for the preparation and evaluation AC from post-consumer office paper. Wastepaper is first gathered and shredded, and then it is prepared by drying and soaking in various concentrations of chemical activation agents (KOH and $ZnCl_2$). Activated carbon is then created by heating the treated paper in a high-temperature furnace. The AC is then cleaned, dried, and crushed into a fine powder. When treating wastewater, the produced AC is mixed with water samples and stirred for a fixed period before being filtered to remove solid particles. Lastly, FTIR analysis is used to determine the functional groups contained in the material and water quality measures, including pH, turbidity, and BOD, are used to evaluate the activated carbon's performance.

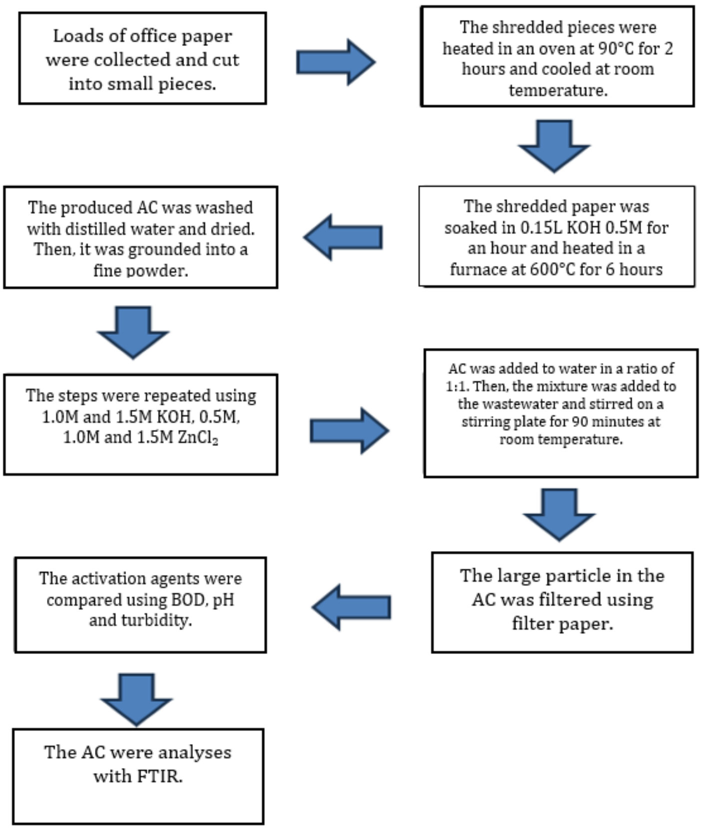

Fig. 1 *Preparation and application of activated carbon from post-consumer paper*

3. Result and Discussion

This section presents the experimental findings on the performance of activated carbon prepared from wastepaper and discusses its effectiveness in improving wastewater quality. The analysis focuses on functional groups using FTIR, BOD reduction, pH changes, and turbidity removal.

3.1 Fourier-Transform Infrared Spectroscopy (FTIR) Analysis of KOH

Fig. 2 shows the overlay of the FTIR spectrum of AC samples prepared using different concentrations of KOH (0.5 M, 1.0 M, and 1.5 M). All three samples exhibited several common characteristic peaks, indicating the presence of similar functional groups such as O-H / N-H stretching (~3640-3200 cm^{-1}), aliphatic C-H stretching (~2920-2850 cm^{-1}), and carbonyl C=O stretching (~1740-1710 cm^{-1}). These peaks suggest the presence of hydroxyl, alkane, and carbonyl groups, which are essential in surface functionalization.

However, variations in peak intensity and sharpness were observed across the samples. The spectrum of KOH 1.5 M demonstrated more intense and broader O-H / N-H and C=O bonds compared to 0.5 M and 1.0 M, implying a higher degree of surface oxidation and functional group enrichment. Additionally, peaks associated with C=C / N-H bending (~1630-1600 cm^{-1}) and aromatic C-H out-of-plane bending (~900-675 cm^{-1}) were more prominent in KOH 1.5 M, suggesting a greater aromaticity and structural complexity. These spectral differences indicate that increasing KOH concentration during activation enhances the formation of oxygen-containing functional groups and aromatic structures, which may improve the adsorption affinity of the AC for pollutants in aqueous solutions.

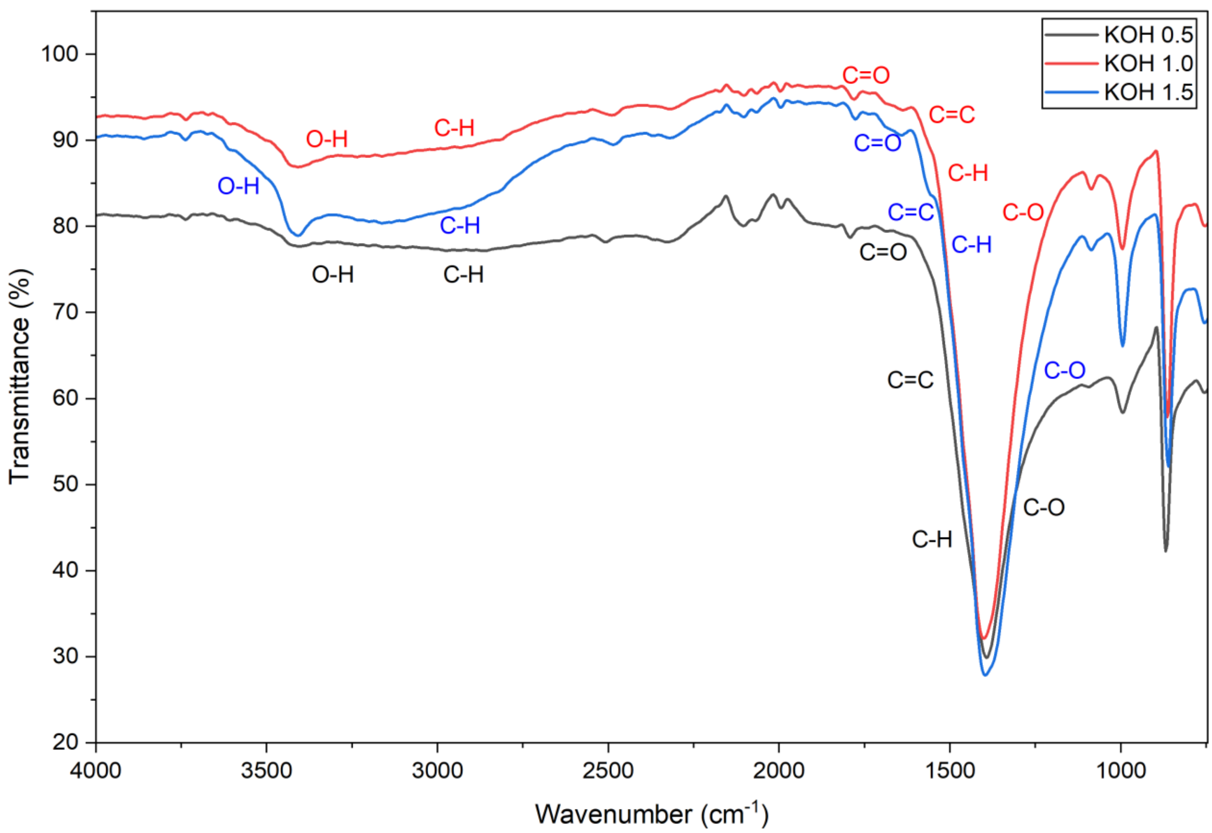

Fig. 2 *KOH transmittance against wavenumber*

3.2 Fourier-Transform Infrared Spectroscopy (FTIR) Analysis of $ZnCl_2$

Fig. 3 shows the FTIR spectra of activated carbon samples treated with varying concentrations of $ZnCl_2$ (0.5 M, 1.0 M and 1.5 M), which exhibited several prominent and overlapping peaks corresponding to key functional groups. A broad absorption band observed around ~3420-3430 cm in all samples indicates the presence of hydroxyl groups (-OH), commonly attributed to adsorbed moisture, alcohol, or phenolic compounds. The characteristics C-H stretching vibrations near ~2920 cm, present in all three spectra, suggest the persistence of aliphatic hydrocarbon chains within the carbon matrix.

A strong peak in the ~1710-1715 cm region corresponds to the C=O stretching vibration, indicating the presence of carbonyl-containing groups, such as ketones, aldehydes, or carboxylic acids. This band became more defined at higher $ZnCl_2$ concentrations, suggesting an increase in surface oxidation or carbon rearrangement. Additionally, overlapping bands in the 1580–1600 cm^{-1} range reflect C=C stretching vibrations from aromatic structures or conjugated systems, which appear increasingly prominent with higher $ZnCl_2$ concentrations, likely due to enhanced aromatization during chemical activation.

C–H bending modes (~1380–1470 cm^{-1}) and C–O stretching bands (~1000–1250 cm^{-1}) are consistently present, indicating the existence of alkyl groups and oxygenated functionalities such as ethers, esters, or alcohols. Notably, low-frequency bands in the region of ~600–900 cm^{-1}, associated with aromatic C–H out-of-plane bending or Zn–O interactions, were more intense in the 1.5 M $ZnCl_2$ sample, suggesting stronger metal–oxygen bonding at higher activating agent concentrations.

Overall, the overlay of the FTIR spectra demonstrates a trend of increasing functional group intensity and structural development with higher $ZnCl_2$ concentration, confirming its role in enhancing the chemical activation and surface functionality of the resulting activated carbon.

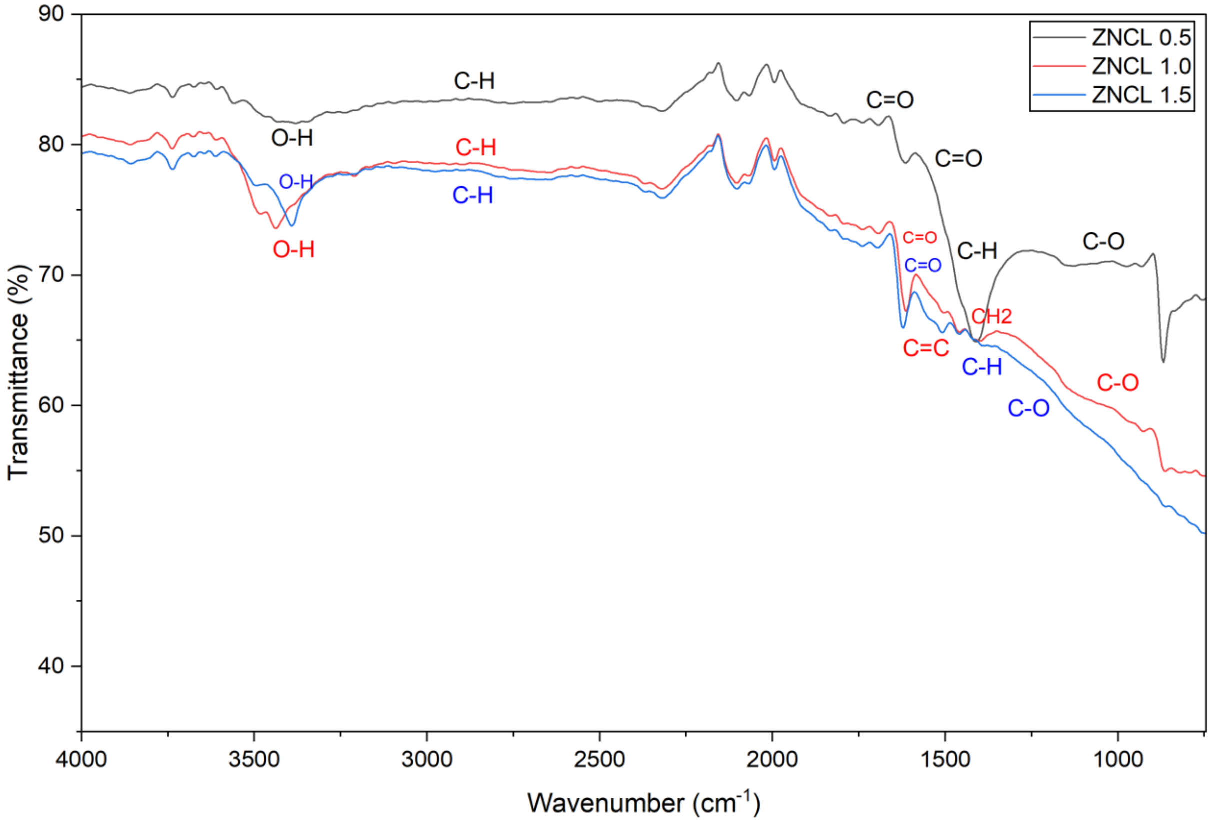

Fig. 3 *$ZnCl_2$ transmittance against wavenumber*

3.3 Biochemical Oxygen Demand (BOD)

BOD is a key indicator of organic pollution in water. It measures the amount of dissolved oxygen microorganisms require to degrade organic matter over a five-day incubation period, commonly referred to as BOD_5 at 20 °C. High BOD levels indicate significant organic load, which can deplete dissolved oxygen and lead to hypoxic conditions unfavourable to aquatic life [9]. In this study, the initial BOD of untreated Sungai Panchor water was 4.2 mg/L. Fig. 4 shows the BOD values of wastewater after treatment with AC made from wastepaper using KOH and $ZnCl_2$ at various concentrations. For KOH, BOD decreased consistently with the lowest value (2.1 mg/L) at 1.5 M, indicating better removal with higher concentration. For $ZnCl_2$, the lowest BOD (1.9 mg/L) was at 1.0 M, with slight differences at other concentrations. This suggests 1.0 M is the optimal $ZnCl_2$ level. Overall, both agents reduced BOD from 4.2 mg/L, with KOH showing a stable trend, and $ZnCl_2$ achieving the lowest value.

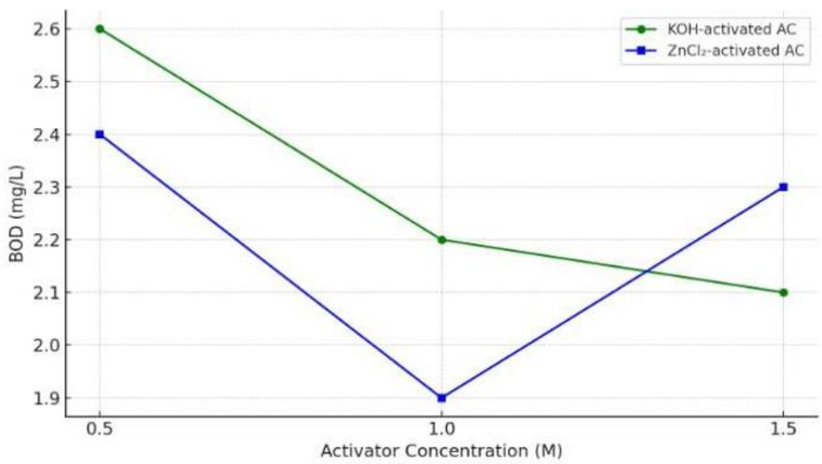

Fig. 4 *BOD readings of KOH and $ZnCl_2$ with different concentrations*

3.4 pH Value

The untreated water from Sungai Panchor had an initial pH of 5.10, indicating a slightly acidic condition unsuitable for most aquatic life and treatment systems.

Fig. 5 shows the variation in pH of treated wastewater based on the concentration of KOH and $ZnCl_2$ used during AC synthesis. KOH-activated carbon increased pH with rising concentration, from 9.85 (0.5 M) to 11.32 (1.5 M), indicating the presence of alkaline surface groups that remain active during treatment. In contrast, $ZnCl_2$-activated carbon showed a decreasing pH trend, from 8.00 (0.5 M) to 6.42 (1.5 M), suggesting acidic characteristics formed at higher $ZnCl_2$ concentrations. These opposite patterns highlight the differing chemical behaviour of both agents, KOH increases alkalinity, while $ZnCl_2$ leads to more acidic effluent at higher concentration.

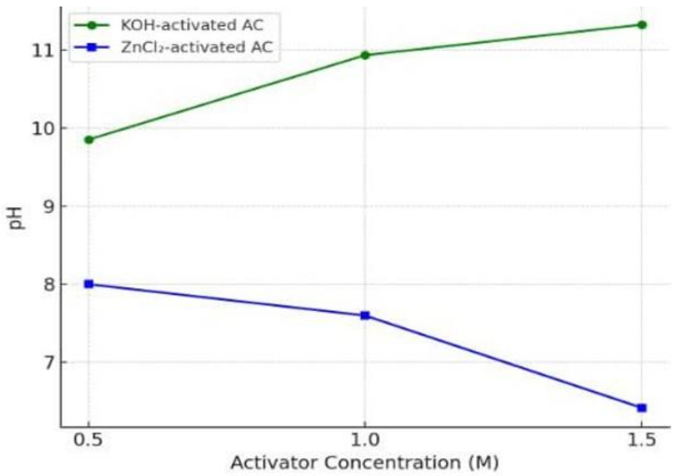

Fig. 5 *pH readings of KOH and $ZnCl_2$ with different concentrations*

3.5 Turbidity

The untreated wastewater had an initial turbidity of 0.81 NTU. Fig. 6 shows turbidity values of treated wastewater using AC synthesized with various concentrations of KOH and $ZnCl_2$. All samples reduced turbidity from the initial 0.81 NTU, confirming effective adsorption. For KOH-AC, turbidity decreased consistently with concentration, reaching 0.39 NTU at 1.5 M, indicating better pore development. For $ZnCl_2$-AC, the lowest turbidity was 0.21 NTU at 1.0 M. Slight increases were observed at 0.5 M (0.26 NTU) and 1.5 M (0.30 NTU), likely due to over-activation effects. $ZnCl_2$ at 1.0 M showed the best turbidity removal, while KOH offered more stable reduction across all concentrations. These findings demonstrate the high potential of paper-based activated carbon for removing suspended particles [11].

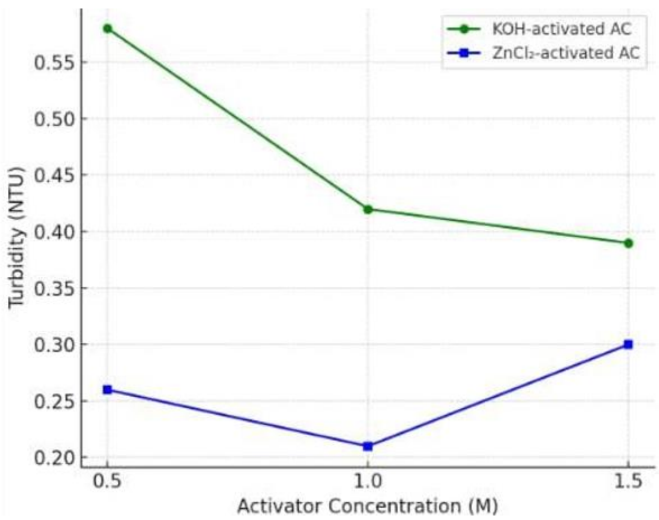

Fig. 6 *Turbidity readings of KOH and $ZnCl_2$ with different concentrations*

4. Conclusion

Preparation and characterization of the activated carbon from post-consumer paper with KOH and $ZnCl_2$ activation are described in this study. The sample treated with $ZnCl_2$ at 1.0 M performed the best out of all the evaluated concentrations and activating agents, achieving the lowest BOD (1.9 mg/L) and turbidity (0.21 NTU) while maintaining a near-neutral pH (6.42–8.00). In most water treatment applications, $ZnCl_2$ maintained a more stable and neutral pH range (6.42–8.00). Meanwhile, KOH-derived carbon also removed pollutants effectively but produced highly alkaline conditions (up to 11.32) at 1.5 M, which may limit its practical use.

Overall, the findings emphasize paper waste's potential as a low-cost precursor for AC, with the added benefits of reducing solid waste and increasing water quality. The results also correspond with circular economy concepts, since they convert discarded paper into a value-added product for environmental conservation. Future study should concentrate on improving activation conditions, exploring other waste-derived precursors, and determining the long-term stability of paper-based AC in various wastewater situations.

Acknowledgement

The authors would like to thank the Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia for its support.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design**: Auni Farahiyah Muhamad Waras, Nur Iman Safina Nazrul Izzad, Nur Nadia Natasya Khairul Ariffin, Norain Ahmad Nordin; **data collection**: Auni Farahiyah Muhamad Waras, Nur Iman Safina Nazrul Izzad, Nur Nadia Natasya Khairul Ariffin; **analysis and interpretation of results**: Auni Farahiyah Muhamad Waras, Nur Iman Safina Nazrul Izzad; **draft manuscript preparation**: Auni Farahiyah Muhamad Waras, Nur Iman Safina Nazrul Izzad, Nur Nadia Natasya Khairul Ariffin, Norain Ahmad Nordin, Nuramirah Juma'at. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] V. A. Tzanakakis, N. V. Paranychianakis, and A. N. Angelakis, "*Water supply and water scarcity*," Water, vol. 12, pp. 2347–2347, Aug. 2020, [Online]. Available: https://www.mdpi.com/journal/water

[2] G. Crini and E. Lichtfouse, "*Advantages and disadvantages of techniques used for wastewater treatment*," Environmental Chemistry Letters, vol. 17, no. 1, pp. 145–155, Jul. 2018, doi: 10.1007/s10311-018-0785-9.

[3] R. Mustafa and E. Asmatulu, "*Preparation of activated carbon using fruit, paper and clothing wastes for wastewater treatment*," Journal of Water Process Engineering, vol. 35, p. 101239, Mar. 2020, doi: 10.1016/j.jwpe.2020.101239.

[4] A. Demirbas, "*Agricultural based activated carbons for the removal of dyes from aqueous solutions: A review*," Journal of Hazardous Materials, vol. 167, no. 1–3, pp. 1–9, Jan. 2009, doi: 10.1016/j.jhazmat.2008.12.114.

[5] Y. A. B. Neolaka et al., "*Potential of activated carbon from various sources as a low-cost adsorbent to remove heavy metals and synthetic dyes*," Results in Chemistry, vol. 5, p. 100711, Dec. 2022, doi: 10.1016/j.rechem.2022.100711.

[6] D. ÖzdemiR, S. Bulbul, and M. E. Ergün, "*Production of activated carbon from the waste paper by chemical activation method*," International Advanced Researches and Engineering Journal, vol. 7, no. 1,pp. 52–61, Apr. 2023, doi: 10.35860/iarej.1222591.

[7] I. Ozdemir, M. Şahin, R. Orhan, and M. Erdem, "*Preparation and characterization of activated carbon from grape stalk by zinc chloride activation*," Fuel Processing Technology, vol. 125, pp. 200–206, May 2014, doi: 10.1016/j.fuproc.2014.04.002.

[8] K. Mabalane, P. M. Thabede, and N. D. Shooto, "*Activated Carbon from Paper Waste as Potential Adsorbents for Methylene Blue and Hexavalent Chromium*," Applied Sciences, vol. 14, no. 11, p. 4585, May 2024, doi: 10.3390/app14114585.

[9] E. M. Enyau, H. Y. Johanis, A. I. F. Roslan, and N. F. A. Ahmad, "*Water quality monitoring and classification at Panchor River*," Multidiscip. Appl. Res. Innov., vol. 4, no. 2, pp. 73–78, 2023, https://publisher.uthm.edu.my/periodicals/index.php/mari/article/view/8413

[10] T. Yamashita et al., "*Energy savings with a biochemical oxygen demand (BOD)- and pH-based intermittent aeration control system using a BOD biosensor for swine wastewater treatment*," Biochemical Engineering Journal, vol. 177, p. 108266, Nov. 2021, doi: 10.1016/j.bej.2021.108266.

[11] C. X. M. Collave, R. J. L. Bacilio, A. E. G. Escobedo, R. F. R. Espinoza, Y. F. A. Liza, and J. M. I. Roña, "*Turbidity and color removal from irrigation water, with coagulants and activated carbon, controlled by an Arduino system*," Case Studies in Chemical and Environmental Engineering, p. 100978, Oct. 2024, doi: 10.1016/j.cscee.2024.100978.