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Evaluating the Efficiency of Wastepaper Activated Carbon in Palm Oil Wastewater Treatment

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Abstract

With the global demand for palm oil on the rise, palm oil mills are generating more secondary effluent (POMSE), a waste product that's rich in organic matter and poses serious environmental concerns. To help tackle this issue, this study investigated using activated carbon made from wastepaper (WPAC) as a green, low-cost way to treat wastewater. The WPAC was created through a chemical process using potassium hydroxide (KOH), involving several steps, which are soaking the paper, drying it, carbonizing it at 600 °C under argon gas, washing it with acid, and finally heating it again to improve its porosity and reactivity. We tested five different amounts of WPAC, ranging from 0.5g to 2.5 g, to see how well it could improve water quality, focusing on colour, turbidity and pH levels. The 2.5 g dose gave the best results for colour, reducing it from 2030 to 493 ADMI. For turbidity, the clearest result is 12.01 NTU at 1.5 g. Interestingly, WPAC also made the water more alkaline, with the highest pH of 9.7 recorded at 2.5 g. To understand how WPAC works, we used FTIR to detect active functional groups responsible for adsorbing pollutants, and SEM to observe its porous surface. Among all the masses, 2.5 g proved the most effective overall, delivering strong results in colour and turbidity reduction, along with a noticeable shift in pH. This study shows that WPAC is not just a clever way to recycle wastepaper. It also offers a practical, eco-friendly solution for treating the palm oil industry.

1. Introduction

Palm oil production is a huge industry, especially in Southeast Asia. However, this growth comes with environmental challenges, particularly from the large amounts of wastewater produced, such as Palm Oil Mill Secondary Effluent (POMSE). POMSE contains oils, suspended solids and organic acids, making it difficult to treat and potentially harmful if left unmanaged [1], [2]. One widely used method for cleaning wastewater is adsorption using activated carbon, a porous material that captures pollutants from water [3]. Traditional activated carbon is often made from coal or coconut shells, which can be costly and not always sustainable [4]. This has led researchers to explore alternative, low-cost sources such as wastepaper.

Wastepaper is rich in cellulose and can be converted into activated carbon through chemical activation, typically using potassium hydroxide (KOH) [5], [6], [7]. The resulting activated carbon made from wastepaper (WPAC) has a porous structure and suitable surface chemistry for capturing contaminants. Using wastepaper as a raw material not only provides a useful second life for discarded materials but also aligns with sustainability and circular economy goals [4], [6].

This study focuses on producing WPAC from wastepaper using KOH activation. It also investigates how effective WPAC is in treating POMSE by evaluating changes in pH, turbidity and colour. Additionally, WPAC's surface structure and functional groups were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) to understand its adsorption properties.

2. Materials and Methods

Fig 1. shows the methodology for producing activated carbon made from wastepaper (WPAC). Waste printed paper was collected from offices at Universiti Tun Hussein Onn Malaysia (UTHM). Next, it was shredded and used as the raw precursor. For activation, 750 g of paper was mixed with 375 g of potassium hydroxide (KOH) and 750 mL of distilled water, then left to soak for 24 hours. The mixture was subsequently oven-dried at 80 °C and carbonized at 600 °C under an argon gas atmosphere. The resulting char was washed with 0.5 M HCl and rinsed with deionized water until a neutral pH was achieved. The final product was dried at 100 °C and ground into a fine powder to obtain WPAC.

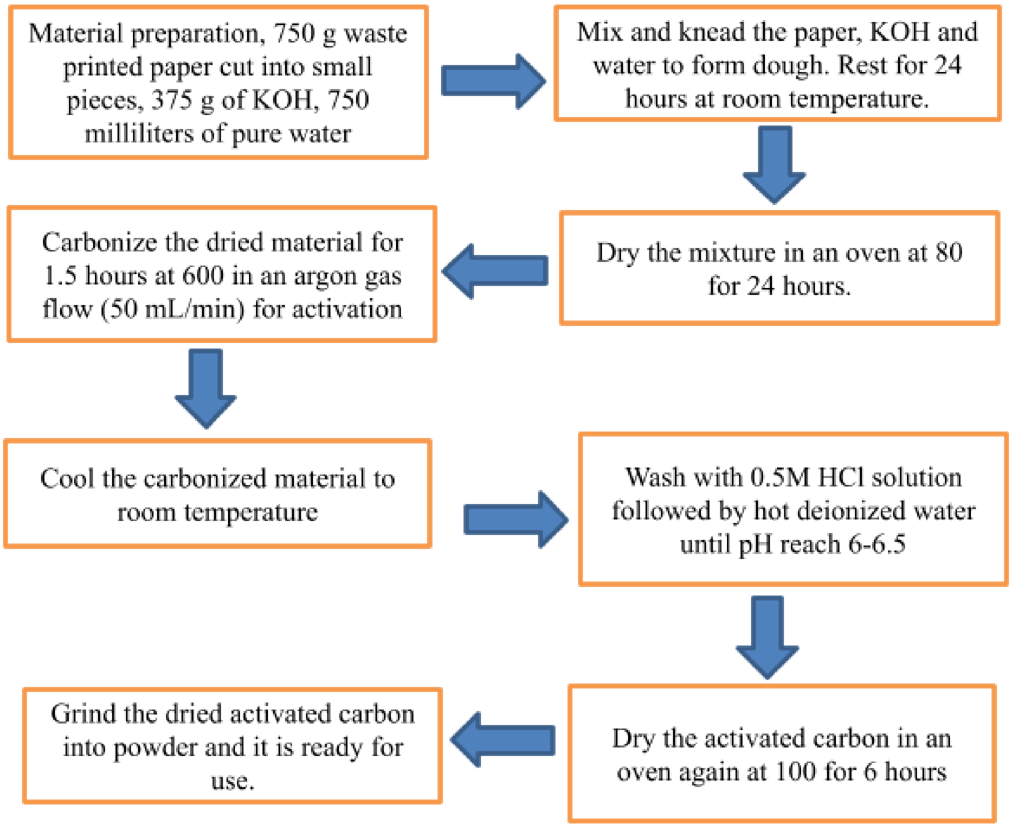

Fig. 1 *Methods to produce WPAC*

Palm Oil Mill Secondary Effluent (POMSE) samples (200 mL each) were treated with WPAC at dosages ranging from 0.5 g to 2.5 g, stirred for one hour, filtered, and analyzed. Water quality parameters were measured using the following instruments: a calibrated pH meter for pH, a turbidity meter for turbidity (NTU), and a DR6000 spectrophotometer for colour (ADMI units). The surface chemistry of WPAC was characterized using FTIR, while surface morphology and porosity were examined using SEM.

3. Results and Discussion

This section examines the effectiveness of activated carbon made from wastepaper (WPAC) in treating Palm Oil Mill Secondary Effluent (POMSE). It highlights WPAC's ability to improve water quality by adjusting pH, reducing turbidity, and reduce colour intensity in the effluent. The results demonstrate that WPAC is a cost-effective and efficient material for improving wastewater quality.

3.1 Performance Evaluation of WPAC in pH, Turbidity, and Colour of POMSE

Table 1 presents the pH values of POMSE samples, untreated and treated with varying masses of WPAC, ranging from 0.5 g to 2.5 g.

Table 1 *pH of treated POMSE with different masses of WPAC*

Sample WPAC Powder (g)	pH level of treated POMSE
0	8.6
0.5	9.1
1.0	9.2
1.5	9.3
2.0	9.3
2.5	9.7

From Table 1, the pH of POMSE was observed to increase progressively with higher amounts of WPAC, rising from 8.6 in the untreated sample to 9.7 at a mass of 2.5 g. This increase is most likely attributed to alkaline residues remaining from the chemical activation process using KOH, a method widely used to enhance the porosity and surface functionality of carbon-based materials [4], [5], [7]. Similar pH-altering effects have been reported in other studies using activated carbon derived from waste materials [4], [5]. While a higher pH can help with some adsorption processes [3], it may also create problems with regulations. The final pH of 9.7 is above the allowed range of 5.5-9.0 set by Malaysia's Department of Environment (DOE) [1], [2]. Therefore, even though WPAC works well in treating POMSE, especially at higher amounts, the treated water may need pH adjustment before it can be safely discharged.

Table 2 *Turbidity of treated POMSE with different masses of WPAC*

Sample WPAC Powder (g)	Turbidity (NTU)
0	5.13
0.5	15.65
1.0	21.75
1.5	10.50
2.0	14.55
2.5	15.40

From Table 2, untreated POMSE had a turbidity of 5.13 NTU, which surprisingly increased when WPAC was added. The highest turbidity was seen at 1.0 g WPAC with 21.75 NTU. This increase might be caused by fine WPAC particles mixing into the water instead of settling properly, a common issue with powdered adsorbents [5], [7]. The best turbidity reduction happened at 1.5 g, dropping to 10.50 NTU, showing that this amount helped remove more suspended solids. However, increasing the dosage beyond that caused turbidity to rise again, possibly due to too much WPAC being added and not fully settling [4], [8]. Overall, 1.5 g WPAC gave the best turbidity result, but more work on mixing and filtering is needed to improve quality.

Table 3 *Colour test of treated POMSE with different masses of WPAC*

Sample WPAC Powder (g)	Colour (ADMI)
0	2030
0.5	727
1.0	715
1.5	638
2.0	540
2.5	493

Table 3 shows that the colour of POMSE decreases notably as the amount of WPAC increases, from 2030 ADMI without treatment to 493 ADMI with 2.5g of WPAC. This indicates that WPAC is highly effective in adsorbing colour causing compounds, which is supported by its porous structure and surface functional group [5]. The findings are consistent with previous research on the efficiency of activated carbon made from waste materials in wastewater treatment [6]. Although greater amounts of WPAC enhance colour removal, the rate of improvement slows down, suggesting a diminishing return at higher dosages.

3.2 FTIR Analysis of WPAC

Fig. 2 shows the results of FTIR analysis of the activated carbon produced from printed paper using KOH as the activating agent. Several distinct transmittance peaks are observed, indicating the presence of various functional groups that contribute to the adsorptive properties of the activated carbon.

The board adsorption band observed around 3400-3600 cm^{-1}, which corresponds to O-H stretching vibrations of hydroxyl groups or adsorbed water. This characteristic broad band is commonly observed in carbon materials activated with strong alkaline agents and indicates surface hydroxylation beneficial for adsorption processes [5]. Peaks around 2900-2950 cm^{-1} correspond to C-H stretching in aliphatic compounds, possibly from residual organics in the precursor material. A visible peak near 1700–1750 cm^{-1} corresponds to C=O stretching, suggesting the presence of carboxylic or lactonic functional groups, which are known to increase surface polarity and binding capacity [3].

In the region between 1600–1650 cm^{-1}, the presence of C=C stretching indicates aromatic structures formed during carbonization, consistent with the partial graphitization process [7]. Additionally, the strong adsorption in the 1000–1300 cm^{-1} region corresponds to C–O bonds (ethers, phenols, and alcohols), which are typical of oxygen-containing surface functionalities developed during chemical activation with KOH [9].

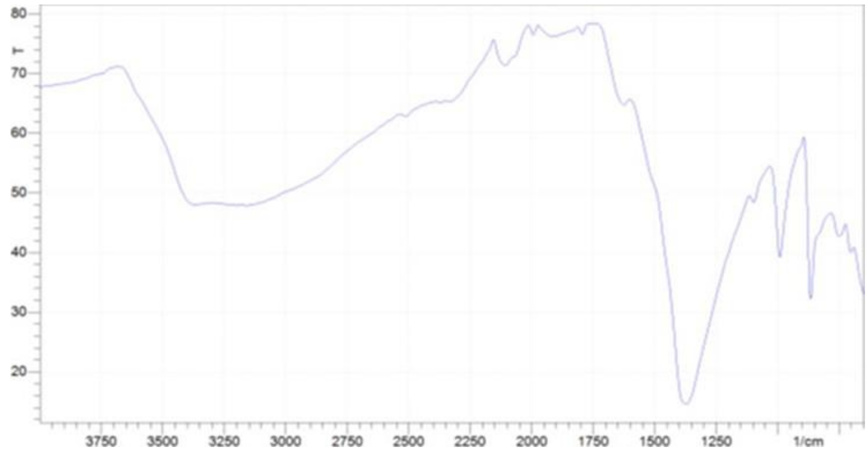

Fig. 2 *Fourier-Transform Infrared Absorbance Spectra (FTIR) analysis of WPAC*

3.3 SEM Analysis of WPAC

Fig. 3 shows the results of surface morphology of the WPAC examined using SEM at 2000× magnification. Analysis of WPAC is shown in Fig. 3. From the SEM micrographs, the image reveals a highly irregular and porous surface, indicating successful activation through chemical treatment with KOH.

The formation of well-developed pore structures is essential for enhancing the adsorption capacity of activated carbon, as it increases the available surface area and facilitates pollutant access to interior binding sites [8]. The presence of micropores and mesopores in carbon-based materials plays important role in capturing organic compounds from water solutions, as these tiny pores provide ample surface area for adsorption to occur effectively [1].

Alkaline activating agents like KOH have also been shown to be highly efficient in creating these porous structures, especially at elevated temperatures. This is because KOH is capable of deeply penetrating the carbon material and expanding its internal structure to form a more developed pore network [7]. Furthermore, adsorption at the microscopic level is largely driven by van der Waals forces, particularly within extremely small (sub-nanometer) pores. The distinct surface features and porosity observed in the WPAC samples indicate that the chemical activation process was successful. These characteristics are crucial in enabling WPAC to effectively remove pollutants from POMSE, making it a promising material for wastepaper treatment

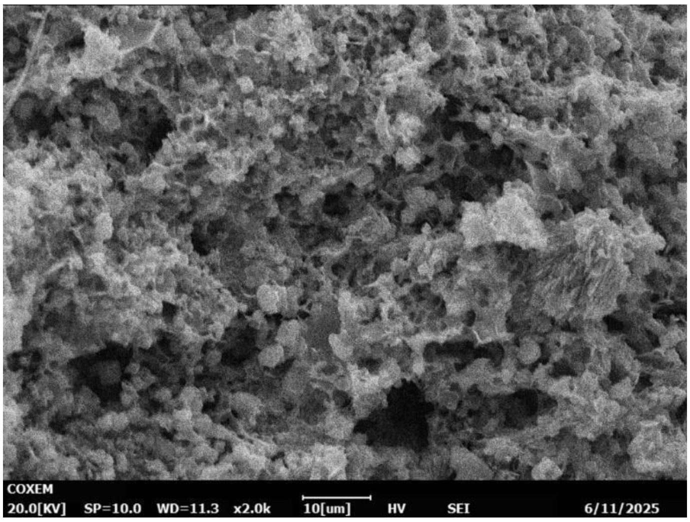

Fig. 3 *SEM analysis of WPAC*

4. Conclusion

The findings clearly show that activated carbon made from wastepaper (WPAC), produced through chemical activation with potassium hydroxide (KOH), is highly effective in treating palm oil mill secondary effluent (POMSE). Analysis using Fourier Transform Infrared Spectroscopy (FTIR) confirmed the presence of key functional groups such as hydroxyl, carbonyl, and aliphatic C-H bonds. These groups indicate that the surface of the WPAC is chemically active and well-suited for attracting and binding pollutants.

The structure of the WPAC, which features well-developed pores and reactive surfaces, enabled strong interactions with contaminants in wastewater. Turbidity was notably reduced to 10.50 NTU at a dosage of 1.5 grams, while colour dropped significantly from 696 to 493 ADMI at 2.5 grams. These results demonstrate WPAC's ability to effectively remove suspended solids and substances responsible for colour in POME.

This strong performance can be attributed to the increased surface area and reactive functional groups formed during KOH activation. In comparison to conventional chemical activators like zinc chloride ($ZnCl_2$), KOH provides a cleaner and more environmentally friendly method. It promotes better surface oxidation and produces fewer harmful residues.

Utilizing wastepaper as the raw material helps reduce production costs while giving value to discarded materials. This strategy supports the concept of waste recovery and fits well within the framework of a circular economy. Overall, WPAC offers a cost-effective and sustainable approach to industrial wastewater treatment, helping to reduce environmental impact while promoting resource efficiency.

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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:*** *Dhia Qhamellia Mohd Redzuan, Nurafiqah Elisa Jaafar, Khairul Hiesyamuddin Khairulnizam, Norhaliza Abu Bakar*; ***data collection:*** *Dhia Qhamellia Mohd Redzuan, Nurafiqah Elisa Jaafar, Khairul Hiesyamuddin Khairulnizam, Norhaliza Abu Bakar;* ***analysis and interpretation of results:*** *Dhia Qhamellia Mohd Redzuan, Nurafiqah Elisa Jaafar, Khairul Hiesyamuddin Khairulnizam;* ***draft manuscript preparation:*** *Dhia Qhamellia Mohd Redzuan, Nurafiqah Elisa Jaafar, Khairul Hiesyamuddin Khairulnizam, Norhaliza Abu Bakar. All authors reviewed the results and approved the final version of the manuscript.*

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