Innovative Solutions for Palm Oil Mills: Activated Carbon Treatment Systems

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INTRODUCTION

Palm oil production plays a significant role in meeting the global demand for oils and fats and can boost a country's economic growth (Parveez *et al.*, 2023). However, it also generates a substantial volume of waste, particularly liquid waste known as palm oil mill effluent (POME). Producing one tonne of crude palm oil from fresh fruit bunches (FFB) requires 5.0-7.5 m^3 of water, with more than half of this water becoming POME (Aljuboori *et al.*, 2014). POME is a thick, brownish liquid with a strong odour, composed of 96% water, 0.7% oil and 4% suspended solids. It contains carotene, pectin, tannin, phenol, and lignin, which give it its distinctive colour. With high levels of oil, grease, solid materials, and elevated biochemical oxygen demand (BOD) and chemical oxygen demand (COD), POME negatively impacts soil and water resources, harming all aquatic plants and animals (Kamyab *et al.*, 2018; Nahrul Hayawin *et al.*, 2022). The discharge of POME into water sources causes pollution issues like eutrophication and reduces sunlight penetration, which limits photosynthesis for aquatic plants. This pollution directly threatens aquatic organisms in water bodies. In response, the Department of Environment (DOE), Malaysia has proposed stringent regulations for treating POME before its final discharge into land or watercourses.

Several treatment methods have been explored for degrading POME, including biological, physical, physicochemical, thermochemical, and integrated approaches (Aryanti *et al.*, 2024; Awang *et al.*, 2024). The primary goal is to reduce BOD, COD, and suspended solids (SS) before discharge. With the DOE proposing stringent regulations for BOD levels below 20 mg L^{-1} and colour limits of 100-200 ADMI, activated carbon techniques have emerged as the most effective solution for colour removal (Mubarak *et al.*, 2023; Nahrul Hayawin *et al.*, 2022; Nor Faizah *et al.*, 2016). This manuscript reviews the latest research on POME remediation, highlighting green and sustainable technologies, with a particular focus on the use of activated carbon.

ACTIVATED CARBON FROM OIL PALM BIOMASS

Activated carbon made from renewable biomass offers a promising alternative for industrial applications. It is environmentally friendly due to its effectiveness in removing pollutants and heavy metals from wastewater, the availability of raw materials, low cost, and ease of production (Zaini *et al.*, 2023). Activated carbon from oil palm biomass is particularly sustainable and cost-effective. Since oil palm biomass is readily available at mill sites, it helps reduce raw material, transportation, and operating costs (Zaini and Jalil, 2021). Oil palm kernel shells (OPKS) are an excellent precursor for activated carbon due to their high density, carbon content, and low ash content (Thangalazhy-Gopakumar *et al.*, 2015). Activated carbon derived from OPKS (AC-OPKS) has been shown to effectively remove organic acids and heavy metals from POME in the final discharge pond before it enters the river (Mubarak *et al.*, 2023; Nahrul Hayawin *et al.*, 2022; Nor Faizah *et al.*, 2016). AC-OPKS is produced by carbonising the biomass to bio-char at temperatures below 500°C, followed by activation at high temperatures (above 800°C) using either physical or chemical methods (Alcañiz-Monge *et al.*, 2022).

A two-in-one carbonisation-activation system has been developed to enhance production efficiency by combining the separate processes of carbonisation and activation into a single integrated system. This patented technology, recognised as state-of-the-art (MY-184811-A) carbonises oil palm biomass while simultaneously producing activated carbon in a self-sustaining process. The resulting activated carbon from OPKS has an impressive surface area of 700-1000 m^2/g. Laboratory and pilotscale continuous tests have shown that this AC-OPKS significantly reduces pollutants in the final discharge of POME.

GREEN TREATMENT OF POME FINAL DISCHARGE: COMBINING BIOLOGICAL PRE-TREATMENT AND ACTIVATED CARBON PROCESSES

The activated carbon system represents an eco-friendly approach to treating POME final discharge without using chemicals. It is based on two key principles: (1) pre-treatment using biological methods and (2) the activated carbon process (*Figure 1*).

The integration of activated carbon with biological pretreatment processes leverages the strengths of both methods. Biological pretreatment reduces the bulk of organic matter, decreasing the load on subsequent treatment stages. Following this, activated carbon adsorption further purifies the effluent by targeting specific contaminants that biological processes may not effectively remove. Biological pretreatment involves either anaerobic or aerobic digestion. Anaerobic digestion, often employed in initial stages, breaks down organic matter in the absence of oxygen, producing biogas. Aerobic treatment follows, using oxygen-consuming microorganisms to further reduce organic content and BOD levels. This step is essential for lowering the overall pollutant load before the effluent undergoes more refined treatment. The activated carbon process involves passing the biologically pretreated effluent through AC-OPKS. This material, known for its high surface area and adsorption capacity, effectively removes remaining organic compounds, colourants, and ammoniacal nitrogen. Key operational parameters include the amount of AC-OPKS (1000-2000 kg), flow rate (30-50 m^3/hr), hydraulic retention time (1-2 days), and treatment duration (11 hr/day) (*Figure 2*).

Studies have shown that this integrated approach can significantly enhance the treatment efficiency of POME. The combined system achieves over 90% removal of BOD, COD, SS, and colour (*Figure 3*). This high efficiency is attributed to the complementary nature of the processes: biological pretreatment effectively reduces the bulk of organic pollutants, while activated carbon adsorption targets the remaining contaminants. The continuous adsorption system in this integrated process ensures a steady and consistent removal of pollutants, maintaining effluent quality that complies with DOE discharge limits. The hydraulic retention time of 1-2 days allows for adequate contact time between the effluent and the activated carbon, ensuring optimal adsorption of contaminants. The treatment schedule of 11 hr/day ensures that the system can handle the continuous inflow of POME, maintaining high treatment efficiency without interruption. The integration of activated carbon with biological pretreatment not only improves the treatment efficiency but also offers significant environmental and economic benefits.

The green process for treating POME final discharge involves several steps:

1. Producing activated carbon from oil palm kernel shells using physical activation.
2. Applying biological treatment with effective microbes in an activated sludge process.
3. Using physical-chemical adsorption through activated carbon for further treatment.
4. Recycling treated POME for backwashing sand filtration and activated carbon.
5. Reusing spent activated carbon either by reactivating it or as an organic fertiliser, which provides beneficial nutrients like nitrogen, phosphorus, and potassium.

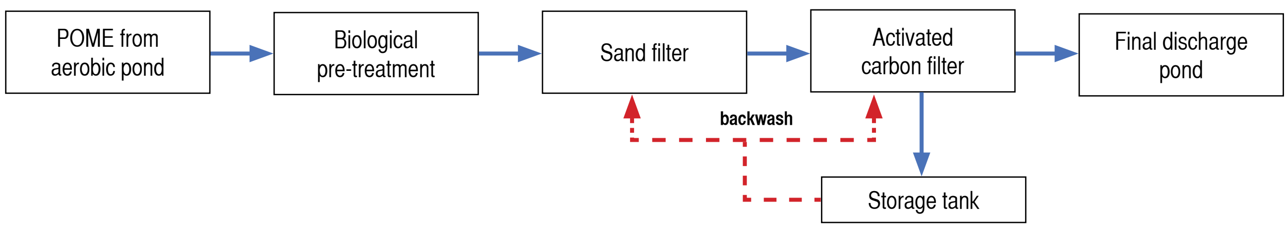

Figure 1. A treatment process for POME.

Figure 2. Successful implementation of integrated POME treatment system at a palm oil mill.

Figure 3. Meeting drinking water standards with integrated activated carbon and biological pretreatment system.

IMPACT OF INTEGRATED ACTIVATED CARBON AND BIOLOGICAL PRETREATMENT ON POME QUALITY

Figure 4 illustrates the improvement in the quality of POME following treatment with an integrated activated carbon and biological pretreatment system. The treatment process effectively reduces turbidity, resulting in a noticeable change in colour from brownish to colourless. This visual change indicates a high removal rate of suspended particles and organic substances that contribute to the water's turbidity. Our findings highlight that although there is no direct correlation between the reduction in colour and BOD decrease, the reduction in colour is significantly influenced by the removal of suspended solids. Previous research supports that colour changes are largely attributable to the presence of suspended solids rather than BOD levels. Therefore, to achieve optimal colour results in POME treatment, it is crucial to first address and reduce suspended solids before applying activated carbon treatment. This integrated approach ensures the treated effluent meets drinking water quality standards, demonstrating the system's effectiveness in enhancing water clarity and overall quality.

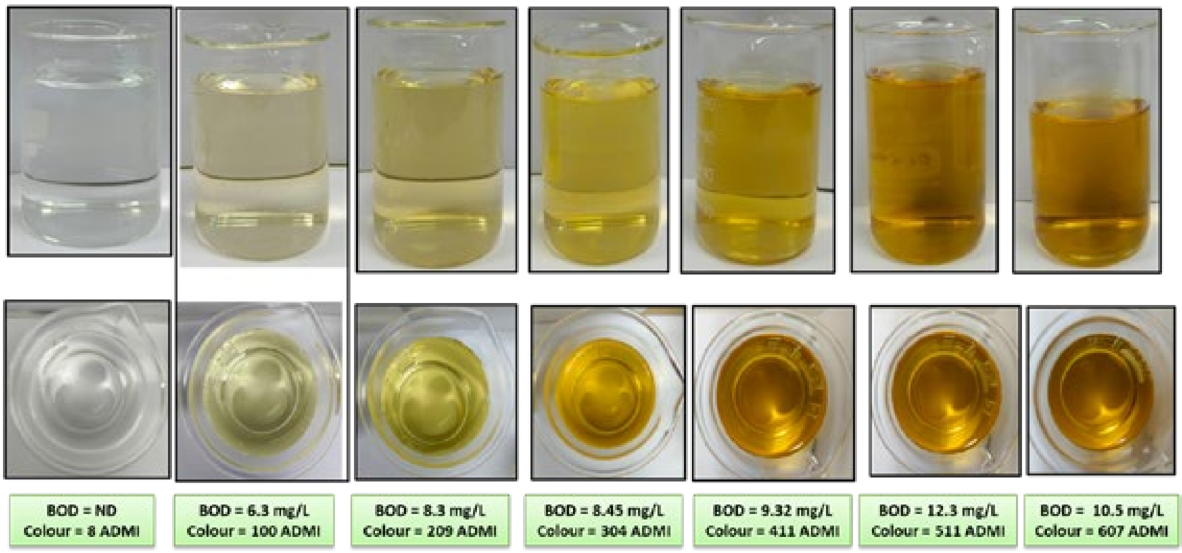

Figure 4. BOD value and color value in POME.

COST BENEFITS OF INTEGRATED POME TREATMENT SYSTEM

The implementation of the integrated activated carbon and biological pretreatment system for POME offers significant cost benefits. A key advantage is the substantial reduction in water costs, with annual savings projected to be between RM50,000 and RM60,000. This cost saving is attributed to the system's efficiency in treating POME to a high standard, reducing the need for additional water resources and minimising treatment expenses. Additionally, the system provides an opportunity for further financial gain through the utilisation of spent activated carbon. This byproduct can be repurposed as biofertiliser, a valuable resource in agricultural applications. With a market value of RM1.00/kg, the sale of spent activated carbon can generate additional revenue. This not only offsets some of the operational costs but also contributes to a circular economy by reusing waste products in a beneficial manner. Overall, the integrated system presents a compelling case for cost-effectiveness and environmental sustainability. The combination of reduced water treatment expenses and potential revenue from spent activated carbon underscores the financial and ecological advantages of adopting this advanced treatment technology.

CHALLENGES AND FUTURE DIRECTIONS

The integration of activated carbon processes with biological pretreatment for POME treatment presents several opportunities for enhancement and future development. Despite its success at a commercial scale, continuous efforts in operational optimisation can further streamline the multi-stage treatment process. This includes training personnel to proficiently manage and maintain the system, ensuring smooth and efficient operation. The management of spent activated carbon offers an avenue for innovation; research into the regeneration and reuse of AC-OPKS can contribute to the sustainability and cost-effectiveness of the process. Additionally, ongoing research is crucial to refine process parameters and explore alternative bioadsorbents that may offer enhanced performance. Emphasising these areas of development will further improve the overall efficiency and sustainability of POME treatment, aligning with the palm oil industry's commitment to environmental stewardship and regulatory compliance.

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