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Development of Alumina-Chitosan Modified Carbon Monolith from Oil Palm Waste: Carbonization and Initial Characterization

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Abstract. *Acid Mine Drainage (AMD) presents significant environmental challenges due to its low pH levels and high concentrations of heavy metals, such as iron (Fe), which pose serious risks to both ecosystems and human health. This research investigates the synthesis and preliminary characterization of activated carbon biosorbents derived from oil palm empty fruit bunches (OPEFB), enhanced with alumina (Al_2O_3) and chitosan. The OPEFB biomass was carbonized at 600°C in an anaerobic environment and processed to achieve a uniform particle size of 200 mesh. SEM characterization revealed non-uniform particle distribution and agglomeration, which impacted pore development. FTIR analysis identified functional groups like silanol, hydroxide, and siloxane, demonstrating the material's adsorption potential. BET analysis indicated a specific surface area of 6.177 m^2/g and a pore volume of 1.567 cm^3/g. Despite the relatively modest surface area, these results provide a basis for further improvements, such as optimizing pore structure and adsorption capabilities. The study underscores the potential of alumina-chitosan modified OPEFB-based activated carbon as an efficient, cost-effective, and sustainable approach for AMD remediation, particularly for Fe removal.*

Keywords: *acid mine drainage, biosorbent, oil palm empty fruit bunches*

1. Introduction

Acid Mine Drainage (AMD) is a critical environmental issue associated with mining activities, both ongoing and abandoned. This problem arises due to high concentrations of harmful elements and extremely low pH levels, often below 3. Such conditions expedite the dissolution of specific minerals, leading to the contamination of surface water, groundwater, soil, and sediments (Abbas et al., 2019). The highly acidic nature of AMD promotes the release of heavy metals like iron (Fe), which is a significant pollutant.

Coal mines are a major source of AMD, particularly rich in Fe. Pyrite (FeS_2), the dominant sulfide mineral in coal mines, undergoes oxidation, resulting in the release of iron ions (Fe^{2+} and Fe^{3+}) into AMD (Chaudhuri, 2022). Iron (Fe) is classified among the three most toxic heavy metals, along with lead and mercury. Excessive Fe concentrations can lead to cellular damage through the generation of reactive oxygen species (Rahimzadeh et al., 2023). Prolonged exposure to heavy metals, including Fe, is associated with severe health risks such as organ failure and metabolic disorders (Fulke et al., 2024). Furthermore, heavy metals in ecosystems can bioaccumulate within food chains, negatively impacting biodiversity and wildlife populations (Ewubare et al., 2024).

Biosorbents offer a promising alternative to traditional methods like chemical precipitation and filtration for the removal of heavy metals. These materials are often derived from waste products, including agricultural residues, making them cost-effective or even free (Georgin et al., 2023). This study introduces the innovative use of oil palm

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empty fruit bunches (OPEFB) as monolithic activated carbon biosorbents. OPEFB-based activated carbon has rarely been utilized in the mining sector to address AMD-related heavy metal contamination, such as Fe. The modification of this activated carbon with alumina (Al_2O_3) and chitosan adds a novel dimension to the research. This study focuses on the preliminary stages of developing OPEFB-based monolithic activated carbon biosorbents, specifically the carbonization process and initial material characterization. The findings will provide a foundation for subsequent research, including material modifications, performance testing, and practical applications in sustainable and efficient waste management.

2. Method

2.1 Equipment and Materials

The equipment used in this study included a high-temperature burner heater (model FB1410M-33) capable of reaching 1100°C, an oven, a desiccator, a ball mill, a sieve shaker, a digital balance, 250 mL Erlenmeyer flasks, 100 mL graduated cylinders, dropper pipettes, a pH meter, a thermometer, and various other glassware. The primary material was a biosorbent derived from OPEFB, which was sourced from a palm oil plantation industry in Nagan Raya Regency.

2.2 Synthesis of Activated Carbon from OPEFB

a. Preparation of Raw OPEFB Material
   The study began with the collection of OPEFB biomass waste produced after palm oil extraction at a processing facility. The biomass was thoroughly washed to remove impurities such as soil, dust, and organic residues and then dried to reduce moisture content that could interfere with the carbonization and activation processes. Drying was conducted in an oven at 105°C for 24 hours. After drying, the material was ground to achieve a uniform particle size before proceeding to the next stage.

b. OPEFB Carbonization Process
   The carbonization of OPEFB was performed under anaerobic (oxygen-free) conditions at a temperature range of 400–800°C. In this study, carbonization was conducted at 600°C for 3 hours (Alam, 2022). At this temperature, most of the organic compounds decomposed, leaving behind a carbon-rich charcoal product. The carbonized material, referred to as OPEFB carbon (C:OPEFB), was sieved to achieve a uniform particle size of 200 mesh. At this stage, the material had basic pore structures but lacked sufficient adsorption capacity, requiring an activation process to enhance pore structure and surface area.

2.3 Characterization of C:OPEFB

The biosorbent C:OPEFB was characterized using several techniques. Scanning Electron Microscopy (SEM) was employed to observe surface morphology and pore structures. Fourier-Transform Infrared Spectroscopy (FTIR) was used to identify chemical functional groups on the carbon surface. Finally, Brunauer-Emmett-Teller (BET) analysis was conducted to determine specific surface area and pore size distribution.

3. Results and Discussions

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3.1 SEM Characterization of C:OPEFB

The SEM analysis results are shown in Figure 1. The characterization revealed uneven particle distribution on the surface, accompanied by agglomeration that contributed to irregular pore formation due to the presence of clustered particles. Previous studies have indicated that calcination temperature plays a critical role in shaping surface morphology and determining particle size. Higher calcination temperatures C:OPEFB led to smaller particle sizes, resulting in denser bonding between particles, increased surface area compactness, and the formation of smaller pores (Hasan et al., 2021; Kurniawan et al., 2014).

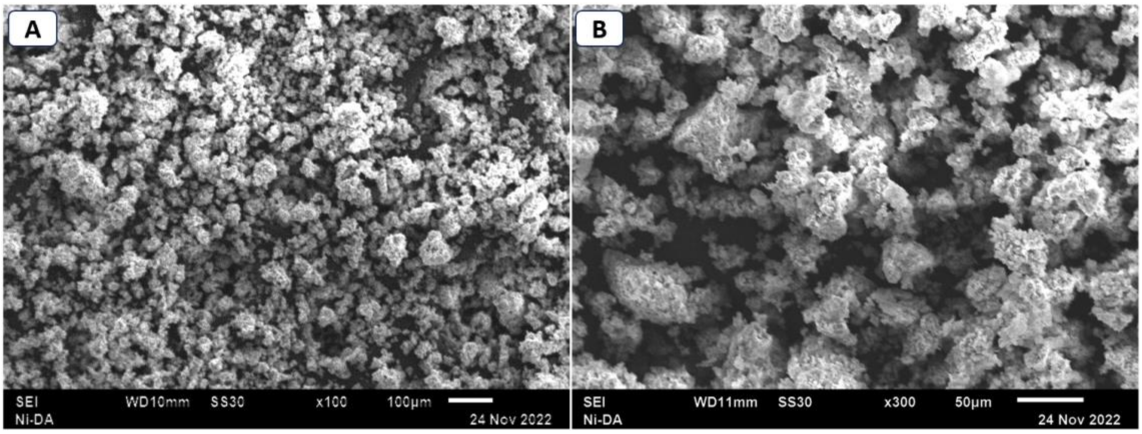

Figure 1. Morphology of C:OPEFB particle sizes from SEM analysis; (A) 100x zoom, (B) 300x zoom

3.2 FTIR Characterization of C:OPEFB

The FTIR analysis was performed to identify the functional groups of silica compounds based on their wave numbers and peak intensities (Hernández-Martínez et al., 2020). The primary goal was to detect the presence of specific compounds by matching functional group absorption peaks and wave numbers with standard values of pure compounds and comparing them to elements present in C:OPEFB (Titus et al., 2019).

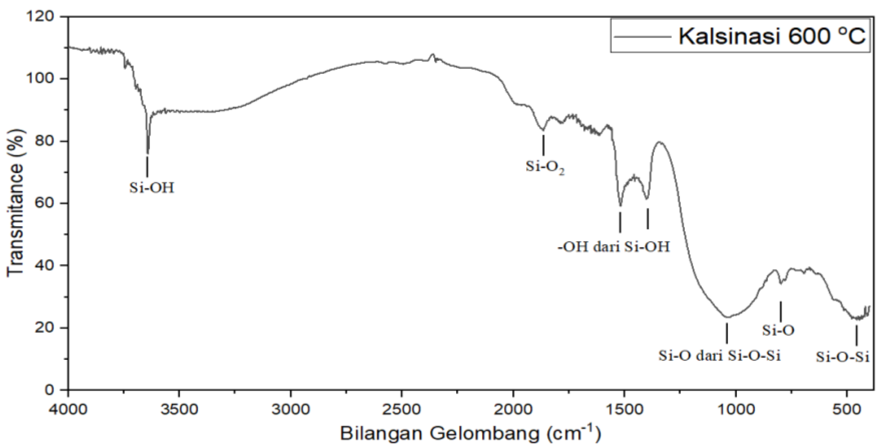

Figure 2. FTIR spectrum results of C:OPEFB particles at 600°C calcination temperature

The analysis identified functional groups such as silanol hydroxide (Si-OH) and H_2O at a wave number of 3643.53 cm^{-1}, Si-O_2 bending vibrations at 1867.09 cm^{-1}, and -OH bending vibrations from silanol (Si-OH) at 1517.98 cm^{-1} and 1398.39 cm^{-1}. Other

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observed vibrations included asymmetric stretching of Si-O from siloxane (Si-O-Si) at 1043.49 cm^{-1}, symmetric stretching of Si-O from siloxane (Si-O-Si) at 798.53 cm^{-1}, and siloxane (Si-O-Si) bending vibrations at 457.13 cm^{-1}. The results of the FTIR spectrum analysis are illustrated in Figure 2.

3.3 BET (Brunauer-Emmett-Teller) Characterization of C:OPEFB

The BET analysis was conducted to evaluate the surface area of the samples and confirm their particulate nature (Zulichatun et al., 2015). For C:OPEFB calcined at 600°C, the analysis revealed a pore volume of 1.567 cm^3/g and a surface area of 6.177 m^2/g. Comparisons with other studies showed similarly modest surface areas for C:OPEFB, such as 10 m^2/g with hydrogen fluoride activation (Tsai et al., 2006) and 6 m^2/g when used as an anode material in lithium batteries (Shen et al., 2012).

4. Conclusions

The biosorbent derived from OPEFB, modified with alumina (Al_2O_3) and chitosan, showed promise as activated carbon for AMD treatment, specifically for adsorbing heavy metal iron (Fe). SEM analysis revealed that the OPEFB-based activated carbon had an uneven particle distribution and agglomeration, which influenced pore formation. FTIR analysis detected chemical functional groups such as silanol, hydroxide, and siloxane, which play a crucial role in enhancing adsorption interactions. BET analysis indicated a specific surface area of 6.177 m^2/g with a small pore volume of 1.567 cm^3/g. While the surface area was relatively smaller compared to other findings, these results lay the groundwork for further development to improve material efficiency. Subsequent research focusing on pore structure refinement and optimization of activation processes is anticipated to increase adsorption capacity and provide a sustainable, cost-effective, and environmentally friendly solution for treating mining waste.

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