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Valorization of Coffee Waste through Zeolite-based Membrane Development for Peat Water Treatment

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ABSTRACT

The availability of clean, consumable water is a fundamental aspect of life. Peat water, commonly found in peatlands and lowland areas, is characterized by high levels of dissolved organic matter, a brownish color, and significant acidity. This study develops a membrane-based filtration system utilizing a combination of coffee grounds and zeolite as the main materials to improve peat water quality. The research involves hydrothermal processing, membrane calibration, and filtration performance evaluation. The study was conducted using three variations in the composition of coffee grounds and zeolite to optimize filtration effectiveness. The analysis results revealed variations in the characteristics of the filtered water based on the membrane composition used. For a 50:50 coffee grounds-to-zeolite ratio, the measured parameters included a pH of 5, TDS of 60 mg/L, turbidity of 16.12 NTU, and electrical conductivity of 156 µS/cm. The 70:30 composition has a pH of 6, TDS of 79 mg/L, turbidity of 12.45 NTU, and electrical conductivity of 158 µS/cm. Meanwhile, the 90:10 composition resulted in a pH of 6, TDS of 62 mg/L, turbidity of 16.48 NTU, and electrical conductivity of 160 µS/cm. A comprehensive evaluation indicated that variations in membrane composition significantly influenced filtration effectiveness, as reflected in changes to water quality parameters such as pH, Total Dissolved Solids (TDS), and turbidity.

1. Introduction

Water scarcity and quality remain pressing global challenges, particularly in regions with unique geological formations such as peatlands. These ecosystems, characterized by their partially decomposed organic matter, present distinct water quality challenges including high acidity, elevated iron content, and significant organic matter concentration that manifests as a distinctive brown coloration (Astiani, 2019). While peatlands serve as crucial water reservoirs, the water derived from these environments typically requires substantial treatment before it becomes suitable for human consumption (Bella et al., 2022).

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In recent years, membrane-based filtration technologies have emerged as promising solutions for water treatment, offering advantages such as room-temperature operation, customizable properties, and environmental sustainability (Lubis et al., 2022). Among the various sustainable solutions for water filtration, spent coffee grounds have emerged as a promising material due to their widespread availability and low cost. These organic waste materials contain active carbon compounds that demonstrate remarkable capability in adsorbing contaminants, particularly organic compounds and heavy metals commonly found in peat water. The repurposing of coffee grounds for water filtration creates a dual benefit, it offers an economical filtration solution while simultaneously contributing to environmental sustainability through waste reduction (Sarasati et al., 2018).

Simultaneously, the growing coffee industry generates substantial quantities of coffee grounds as waste, while naturally occurring zeolites present untapped potential for water filtration applications. Zeolite, a porous material with dominant mineral content, also offers excellent potential for water filtration. Its adsorption capacity can be enhanced through activation using strong acid or base solutions. Zeolite's highly regular crystalline structure, interconnected cavities, and large surface area make it an effective adsorbent. Activation improves its physical and chemical properties, such as surface acidity and porosity, enhancing its performance as a membrane material (Emelda et al., 2013).

This study explores the development of an innovative membrane-based filtration system that combines coffee grounds and zeolite for peat water treatment. The integration of these materials harnesses both the natural porosity of spent coffee grounds and zeolite's exceptional ion-exchange properties, creating a comprehensive approach to water quality enhancement. Beyond improving key water quality parameters such as pH levels, Total Dissolved Solids (TDS), and turbidity, this research also demonstrates the broader potential of combining organic waste materials with natural minerals in sustainable water treatment solutions.

2. Research Method

2.1. Materials

Coffee grounds were obtained as post-brewing waste from local coffee shops. The grounds were thoroughly cleaned and dried at 250°C for 2 hours. Peat water samples were collected from local peatland areas in Muaro Jambi. The samples were stored in clean, sealed containers at room temperature and characterized for initial parameters including pH, turbidity, and Total Dissolved Solids (TDS) before treatment. Zeolite was sourced from commercial suppliers in granular form. Prior to use, zeolite were sieved to achieve uniform particle size distribution.

2.2. Preparation of Zeolite-Modified Coffee Waste Membranes

The membrane preparation involved combining coffee grounds and zeolite at three different ratios (50:50, 70:30, and 90:10 by weight) in reactor tubes. The mixtures underwent hydrothermal treatment at 250°C for 2 hours. Following the heat treatment, the resulting membranes were stabilized in a desiccator for 15 minutes before being ready for use in filtration experiments.

The calibration of the coffee grounds-zeolite membrane was carried out to ensure its readiness and optimal performance for peat water filtration. Membranes of coffee grounds and zeolite were carefully placed into designated membrane holders. Clean water was prepared as the calibration medium, and the filtration process was initiated by activating the water pump. As water passed through the membrane, the filtered water was collected in a separate container for visual assessment. The calibration process continued until the filtered water appeared clear, at which point the pump was turned off. This step ensured that the membrane was adequately prepared and capable of effective filtration before being applied to actual peat water samples. Peat water was pumped through the membrane, and the filtered water was collected in a separate container for analysis.

2.3 Analysis

The analysis of the filtration results focused on key parameters, including pH, Total Dissolved Solids (TDS), turbidity, electrical conductivity (EC).

3. Result and Discussion

The study investigated the effectiveness of composite membranes made from zeolite and coffee waste for treating peat water. The research examined three different mixing ratios of these materials: 50:50, 70:30, and 90:10 by weight, comparing their performance against untreated peat water. Initially, the untreated peat water showed neutral characteristics with a pH of 7, containing moderate dissolved solids (TDS) of 79 mg/L, and relatively high turbidity at 18.28 NTU. The electrical conductivity was measured at 138 μS/cm, indicating the presence of dissolved ionic compounds. When treated with different membrane compositions, interesting patterns emerged. Figure 1 shown the turbidity in peat water at various ratios of zeolite- coffee waste membrane. The membrane with 70% coffee waste and 30% zeolite demonstrated notable results in turbidity reduction.

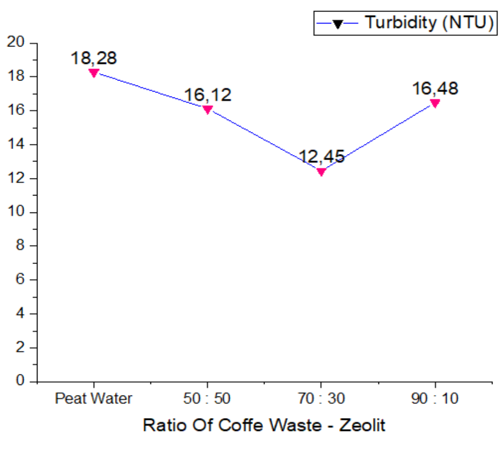

Figure 1. Turbidity in Peat Water at Various Ratios of Zeolite- Coffee Waste Membrane

This ratio successfully decreased turbidity to 12.45 NTU, representing a significant improvement in water clarity. Research by Noorin indicated that composite materials made from spent coffee grounds and zeolite can effectively remove dyes and phosphates from water, suggesting that similar mechanisms could be leveraged for turbidity reduction in peat water (Noorin, 2024). The membrane achieved a turbidity value of 16.12 NTU for the 50:50 ratio. While this represents a reduction from the initial peat water turbidity of 18.28 NTU, the improvement was modest compared to the 70:30 ratio. The 90:10 ratio showed a turbidity value of 16.48 NTU, which was actually higher than both the 70:30 and 50:50 ratios. This increased turbidity could be attributed to the very high proportion of coffee waste, which might result in a less stable membrane structure with fewer zeolite binding sites available for particle capture (Kang et al., 2014).

The impact of varying coffee waste-zeolite membrane ratios on Total Dissolved Solids concentration in peat water treatment was investigated, as illustrated in Figure 2. The 50:50 ratio membrane showed the lowest TDS value of around 60 PPM, indicating the best performance in reducing dissolved solids. When using the 70:30 ratio membrane, the TDS actually increased slightly to about 80 PPM, which was similar to the initial peat water concentration.

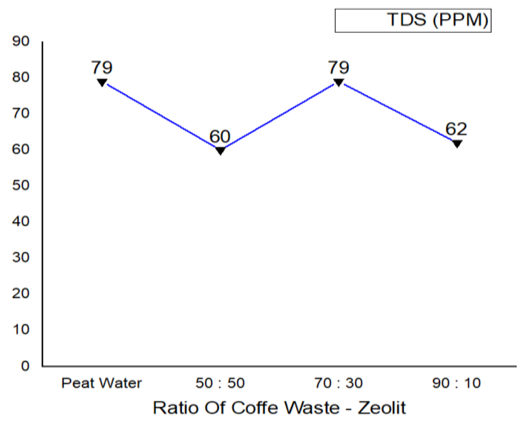

Figure 2. Total Dissolved Solids (TDS) Concentration in Peat Water at Various Ratios of Zeolite- Coffee Waste Membrane

The electrical conductivity measurements in peat water treatment using coffee waste-zeolite membranes shown in Figure 3. The initial EC value of raw peat water was 138 μS/cm, which increased consistently with higher proportions of coffee waste in the membrane composition. Treatment with the 50:50 ratio membrane resulted in an EC value of 156 μS/cm, showing a significant increase from the raw water. This trend continued with the 70:30 ratio, which produced an EC of 158 μS/cm, and the 90:10 ratio, reaching 160 μS/cm. The steady increase in

EC values suggests that the coffee waste component of the membrane might be releasing ionic substances into the treated water.

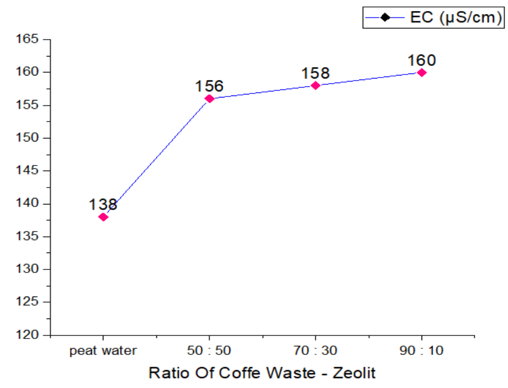

Figure 3. Electrical conductivity in Peat Water at Various Ratios of Zeolite- Coffee Waste Membrane

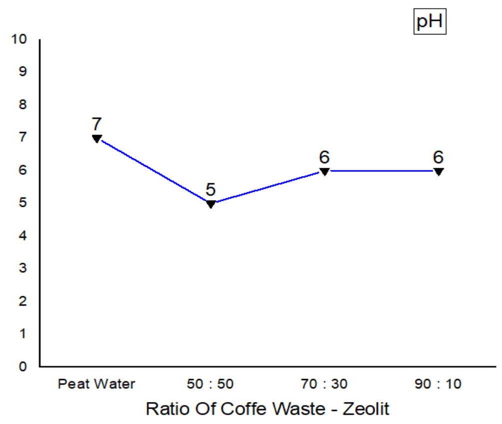

Figure 4. pH in Peat Water at Various Ratios of Zeolite- Coffee Waste Membrane

The treatment of peat water using coffee waste-zeolite membranes is illustrated in Figure 4. The initial pH of untreated peat water was approximately 7, indicating neutral conditions. After treatment with different membrane compositions, the pH values shifted toward slightly acidic levels. The 50:50 ratio membrane showed the most pronounced effect, reducing the pH to around 5. When the coffee waste content was increased in the 70:30 and 90:10 ratios, the pH values remained stable at approximately 6. This decrease in pH from neutral to slightly acidic conditions is likely due to organic acids present in the coffee waste component of the membrane.

4. Conclusion

This study demonstrated the potential of composite membranes made from coffee waste and zeolite for peat water treatment. The results showed that the membrane composition significantly influenced turbidity reduction, TDS concentration, electrical conductivity, and pH levels of the treated water. The 70:30 coffee waste-zeolite membrane achieved the best turbidity reduction, decreasing it to 12.45 NTU, thus significantly improving water clarity. In contrast, the 50:50 ratio membrane performed best in reducing total dissolved solids to 60 mg/L, highlighting its efficiency in removing dissolved impurities. However, as the proportion of coffee grounds increases, the electrical conductivity increases, which is due to the release of ionic compounds, and the pH shifts from neutral to slightly acidic due to the presence of organic acids in the coffee grounds.

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