UNIVERSITI TEKNOLOGI MARA

DEVELOPMENT AND OPTIMIZATION OF PALM KERNEL SHELL ACTIVATED CARBON BLENDED WITH XEROGEL FOR SO2 CAPTURE: EXPERIMENTAL, ISOTHERMS, AND KINETIC STUDIES

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ABSTRACT

The The rapid expansion of palm oil production has generated significant quantities of palm kernel shells (PKS), a waste by-product that poses environmental challenges. Similarly, sulphur dioxide (SO2), a major pollutant from fossil fuel combustion, contributes to respiratory health issues, acid rain, and economic burdens due to healthcare and industrial maintenance. This study addresses both concerns by developing a blend of adsorbents derived from PKSB to efficiently capture SO2 emissions. The hybrid material, combining activated carbon (PKSAC) and xerogel (PKSX) produced via a sol-gel process, exhibited superior structural and adsorption properties. Comprehensive characterization using Brunauer-Emmet Teller (BET) the pore Size for the (PKSB, PKSAC, and PKSX) was 2.177, 1.877, and 16.525 (nm), respectively. Thermo gravimetric analysis (TGA) lower mass loss and higher thermal stability of PKSAC and PKSX indicate more carbonaceous, stable structures, which favour SO2 adsorption by providing enhanced surface area and thermally resilient active sites. Fourier Transform Infrared (FTIR) the stronger and sharper peaks (e.g., around 3300 cm^1, 1630 cm^1) in PKSAC and PKSX suggest the presence of more active oxygenated and acidic surface groups, enhancing SO2 binding via chemisorption or physisorption mechanisms. Scanning Electronic Microscope (SEM) the SEM image shows a highly porous surface structure with interconnected channels, indicating a well-developed porous network. This morphology is favourable for gas adsorption applications such as SO2 capture. X-ray Diffraction (XRD) analysis revealed a characteristic broad peak around 29 = 20-30° for all samples, including xerogel, activated carbon, and biochar. This pattern indicates the amorphous (low-crystallinity) nature of these materials. The observed structural features confirm their suitability for SO2 adsorption applications. Adsorption performance was assessed using a packed fixed-bed column system under varying adsorbent weights and flow rates. A Response Surface Methodology (RSM) model employing a Box-Behnken Design (BBD) was used to optimize key operational parameters: contact time (10-15 minutes), adsorbent mass (10-20 g), and flow rate (100-300 L/h). Under optimal conditions—20 g of adsorbent, a flow rate of 100 L/h, and a 20-minute contact time—removal efficiencies of 84%, 89%, and 91% were achieved using PKSAC, PKSX, and their 30:70 blend, respectively. The experiments were conducted with an SO2 concentration of 50 ppm. The correlation coefficient (R^2) was used to assess the equation's suitability. The PKSAC-PKSX blend is the major contributor to SO2 capture and is utilized to investigate both physisorption and chemisorption interactions between SO2 gas and the blend. The PKSACX adsorption processes are suit both the pseudo-first and pseudo-second order models. This indicates that throughout the adsorption process, both physisorption and chemisorption occur. Kinetic studies revealed the adsorbent's dual physisorption and chemisorption mechanisms, with Thomas and Yoon-Nelson models providing the best fit. This research underscores the potential of PKS-derived hybrid adsorbents as a sustainable and cost-effective solution for SO2 mitigation, offering promising applications in pollution control and waste valorisation.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

On Palm Kernel Shell (PKS) biomass is a residual material derived from the palm oil industry, possessing a wide range of applications and associated benefits. Below are few examples: The utilisation of PKS biomass as a renewable energy source is highly advantageous owing to its significant calorific value (Handaya et al., 2022). Solid biomass can serve as a viable fuel source in biomass power plants, facilitating the generation of electricity. PKS biomass is frequently obtainable at a reduced expense in comparison to alternative biomass fuels, rendering it a cost-effective fuel option. The local sourcing of palm oil, which is a by-product of the industry, might result in a reduction of transportation expenses by minimizing the need to import or transport raw materials over long distances. The cost-effectiveness of biomass renders it a compelling alternative for enterprises and power plants seeking to transition to this renewable fuel source. The combustion of PKS biomass results in the emission of Carbon Dioxide (CO2) into the Earth's atmosphere, so contributing to carbon neutrality. Nevertheless, it is worth noting that the carbon emissions resulting from the combustion of Palm Kernel Shells (PKS) are considered carbon neutral due to the CO2 absorption by palm trees throughout their growth (N. Zeng & Hausmann, 2022).

Palm kernel shell biochar (PKSB) refers to a specific form of biochar that is derived by the process of carbonization of palm kernel shells. The development of a safe and optimal setting is of utmost importance for the health and sustenance of many life forms, including human beings, animals, plants, and diverse aquatic and terrestrial species. The presence of pollutants in highly harmful situations can lead to the occurrence of air pollution, while these same pollutants have the potential to dissolve in rivers and give rise to various forms of pollution. Moreover, the ecosystem is at risk due to the discharge of dangerous chemicals into the environment, primarily from industrial operations, especially those coming from waste streams (Naidu et al., 2021). The Clean Air Act of 1970 designated six specific air pollutants as criterion pollutants. Sulphur dioxide (SO2) is among the six air pollutants, the remaining five being carbon monoxide, lead, nitrogen dioxide, ozone, and particle matter.