UNIVERSITI TEKNOLOGI MARA

ENHANCING CO_2 CAPTURE USING NOVEL ADSORBENTS DERIVED FROM PALM KERNEL SHELL BIOCHAR: EXPERIMENTAL STUDY, PROCESS OPTIMISATION, ADSORPTION ISOTHERM AND KINETIC MODELLING

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ABSTRACT

The urgent need to mitigate anthropogenic (CO_2) emissions, which have increased from pre-industrial levels of 270 ppm to over 410 ppm, underscores the importance of developing efficient and cost-effective carbon capture technologies. This study addresses this challenge by developing high-performance (CO_2) adsorbents derived from Palm Kernel Shell Biochar (PKSB). A Xerogel (PKSBX) was synthesised from (PKSB), while commercial Activated Carbon (PKSB-AC) was also evaluated in a packed fixed-bed column system. The physicochemical properties of the adsorbents were characterized using Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), Brunauer–Emmett–Teller (BET) surface area analysis, Fourier-Transform Infrared Spectroscopy (FTIR), Thermogravimetric Analysis (TGA), and Elemental Analysis (EA). The (CO_2) adsorption process was optimised by varying the adsorbent mass (10 g, 15 g, 20 g), gas flow rate (100 L/h, 200 L/h, 300 L/h), and contact time (5min, 10 min, 15 min) at 30 °C and an inlet (CO_2) concentration of (95.11 ppm). Response Surface Methodology (RSM) was successfully applied to model and optimise the operational parameters, yielding a highly accurate model ($R^2 = 0.99$) for both (PKSBX) and (PKSB-AC). The (RSM) analysis identified a mass weight of (20 g), a flow rate of (100 L/h), and a contact time of (15 min) as the most significant factors influencing adsorption performance for high removal effectiveness of (CO_2). Under these optimal conditions, maximum (CO_2) adsorption efficiencies of (89.2%) for (PKSBX) and (84.5%) for (PKSB-AC) were achieved. Although experimental results indicated the highest removal efficiency at (20 g), the statistical model suggested that (10 g) provided comparable performance with improved material efficiency, reflecting a trade-off between adsorption capacity and cost-effectiveness. Fixed-bed modelling using the Thomas and Yoon–Nelson models confirmed enhanced adsorption efficiency at (20 g) of adsorbent weight and (100 L/h) flow rate. At the same time, kinetic analysis indicated conformity to the pseudo-second-order model, suggesting chemisorption as the dominant mechanism. Blended adsorbents comprising (PKSBX+PKSB-AC) in ratios of (70:30), (50:50), and (30:70), respectively, were further tested. Among these, the (70% PKSBX + 30% PKSB-AC) blend exhibited the highest CO_2 removal efficiency (RE = 92.7%), followed by (89.6%) and (89.2%) for the (50:50) and (30:70) blends, respectively at same operating conditions and parameters values of adsorbent weight (20 g), gas flow rate (100 L/h) and (15min.) of contact time, confirming the superior CO_2 affinity of the Xerogel component. Overall, the study demonstrates that (PKSB)-derived materials, particularly (PKSBX) and its blends with (PKSB-AC), are sustainable and highly effective adsorbents for (CO_2) capture, contributing to both agricultural waste valorisation and climate change mitigation.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

A secure environment is essential for all living organisms, including humans, animals, vegetation, and aquatic and terrestrial species. However, environmental degradation has accelerated in recent decades due to anthropogenic activities, especially industrial operations. These activities release large amounts of greenhouse gases (GHGs) - such as CO_2, CH_4, and NO_2- into the atmosphere, leading to ecosystem disruption and biodiversity loss, and they can also dissolve in water bodies, creating secondary pollutants that harm marine and riverine environments [1]. Large amounts of these emissions are (GHG), and mainly (CO2) gas emissions. (CO2) is a crucial human-caused greenhouse gas, primarily due to its considerable presence and its capacity to persist in the atmosphere for thousands of years. (CO_2) emissions from the sources of anthropogenic activity are increasing to high levels [2]. Figure 1.1 shows the global emissions by sector.

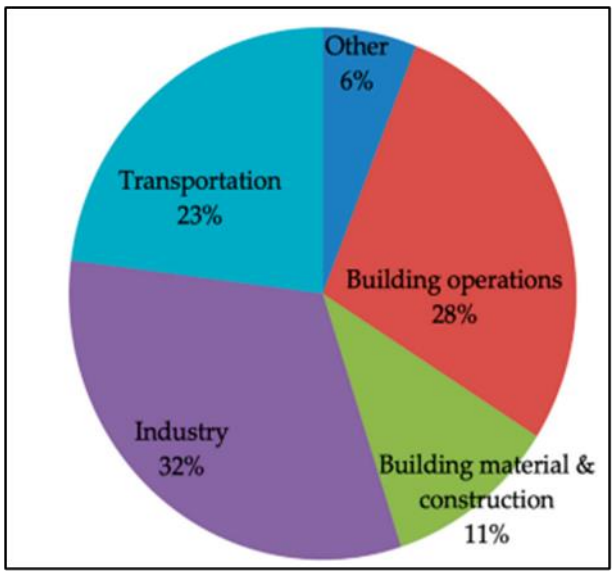


Figure 1.1 Global CO_2 Emissions by Sectors [3]

Recently, attention to climate change has been raised in the international community. It has encouraged the study of technologies aimed at reducing emissions of greenhouse gases, including (CO_2) (CH_4) (NO_2) and others, which contribute to global warming and climate change [4] [5].