Abstract

The increasing concentration of atmospheric CO_2 necessitates sustainable sorbent materials for efficient carbon capture . This thesis explores the valorization of carbon-intensive waste streams into porous carbons for CO_2 capture within a circular materials framework. Three structurally distinct precursors were investigated: woody biomass, recovered carbon black from end-of-life tires, and graphite from spent lithium-ion batteries. Potassium-assisted chemical activation served as a unifying synthesis approach to establish structure–property–performance relationships and assess the chosen materials suitability as solid adsorbents.

The effects of precursor structure, activation conditions, and potassium speciation on pore development, carbon framework evolution, and surface chemistry were systematically analyzed. Particular attention was given to adsorption-relevant microporosity and its role in governing CO_2 uptake and CO_2/N_2 selectivity.

The obtained results suggested that activation responsiveness was strongly precursor-dependent. Biomass showed the highest reactivity toward KOH, yielding dense microporous networks with BET surface areas up to 2655 $m^2\ g^{-1}$ and high CO_2 capacities, although excessive activation caused pore widening and performance loss. Recovered carbon black exhibited limited activation due to its compact morphology, leading to mesopore-dominated structures and lower uptake. Recovered graphite was the most resistant, with porosity developing mainly through defect-driven edge etching while preserving graphitic order.

CO_2 adsorption across all systems was governed by the presence of narrow micropores rather than total surface area, highlighting that the key performance factor was pore size matching to the kinetic diameter of CO_2 as. KOH provided the highest activation efficiency, while alternative potassium salts enabled milder pore development with improved yield. Oxygen-containing surface groups formed as a result of the activation contributed to adsorption energetics but remained secondary to textural effects under physisorption-controlled conditions.

Biomass- and recovered carbon black–derived carbons showed stable cyclic operation and favorable CO_2/N_2 selectivity under dilute and flue-gas-relevant conditions.

Beyond adsorption performance, this work demonstrates scalable routes for converting renewable, industrial, and technological carbon residues into high-value porous materials. The results provide design guidelines for precursor selection, activation strategy, and pore engineering in waste-derived carbons for gas separation and related environmental applications.

Keywords: Activated carbon; Waste valorization; Potassium activation; Recovered carbon black; Recovered graphite; Biomass; CO_2 capture; CCU, CCUS.