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Development of activated carbons from South African coal waste for application in natural gas storage

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ABSTRACT

Every year, South African coal sector generates over 60 million tons of coal waste, which are landfilled in discard dump and slurry ponds. The stockpile of this waste "resource" poses a severe danger to public health, the environment and the socio-economic development of the coal mining region. Therefore, there is an urgent need for an innovative strategy to coal waste reuse and recovery.

In this study, the potential of three South African coal waste samples (run-of-mine fines, discard and flotation slurry) were examined in synthesizing an activated carbon for application in natural gas storage. Activated carbons were prepared by KOH activation, and the impacts of KOH/sample weight ratio and temperature on the activated carbon adsorptive characteristics were examined and optimized using Response Surface Methodology (RSM). The results obtained indicated that with an increased temperature and KOH/sample weight ratio, the surface area and pore volume of the resulting activated carbon increased. The activated carbon with the highest surface area and pore volume from each of the samples were obtained at a temperature of 800 ^{o}C and KOH/sample weight ratio of 4:1.

The morphology, textural characteristics and elemental composition of the activated carbons produced were compared. The synthesized activated carbons were characterized by nitrogen at 77 K adsorption – desorption isotherms and SEM/EDS characterization. Surface area of 1925.34 m^2/g, 1826.41 m^2/g, 1484.96 m^2/g, pore volume of 1.26 cm^3/g, 1.21 cm^3/g, 1.03 cm^3/g and pore size of 2.90 nm, 2.66 nm and 2.51 nm were obtained for activated carbon from run-of-mine fines, discard and slurry, respectively. The SEM/EDS analysis showed pore development and high carbon content. The XRD evaluation confirms the activated carbons as amorphous. The presence of a hysteresis loop in the nitrogen isotherms and the pore size distribution (PSD) confirms highly porous activated carbons consisting of micropores and mesopores.

The characteristics of methane (the major constituent of natural gas) adsorption onto the activated carbons produced are measured for temperatures ranging from 0 to 50 ^{o}C, and pressures up to 40 bar. For this measurement, activated carbon with the highest surface area and pore volume from each of the coal waste samples was used. The activated carbon produced from the run-of-mine fines (ACR) offers a greater adsorption capacity due to its higher surface area and pore volume.

Three adsorption isotherm models (Langmuir, Toth, and Dubinin-Astakhov) were used to validate the measured adsorption data and the Dubinin-Astakhov isotherm model was found to be the most appropriate. The model described the measured data with an average regression error of less than 1% for all the three activated carbon samples. The impact of diffusion on adsorption kinetics was determined in relation to the time taken to achieve equilibrium for the methane/activated carbon system using a mass balance equation that defines pore and surface diffusion. The findings indicate the relationship between the adsorption kinetics, diffusivity, and temperature. An increase in temperature for the methane/activated carbon system was noted to cause an increase in diffusivity, thus reducing the time taken to attain equilibrium. The study indicated that adsorption characteristics (isotherm and kinetics) are the key information in designing and analysing an adsorbed natural gas storage (ANG) system.

An adsorption system using the activated carbons produced as the adsorbent bed was simulated using Aspen Adsorption Software (Adsim). In this study, adsorption capacity was found to be significantly increased by a lower flowrate. This enhances thermal stability and maximizes the quantity of gas adsorbed on the bed. The simulation shows that an ANG storage system's efficiency depends on the suitable selection of adsorbent, inlet flow conditions, and bed geometry.