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Optimization of the synthesis and performance of Polyaspartamide (PAA) material for carbon dioxide capture in South African coal-fired power plants

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Abstract

Global climate change is among the major challenges the world is facing today, and can be attributed to enhanced concentrations of Greenhouse Gases (GHG), such as carbon dioxide (CO_2), in the atmosphere. Therefore, there is an urgent need to mitigate CO_2 emissions, and carbon capture and storage (CCS) is amongst the possible options to reduce CO_2 emissions. Against this background, this work investigated the synthesis and performance evaluation of Polyaspartamide (PAA) adsorbent for CO_2 capture. In particular, the effect of the presence of water-soluble amines in the amine-grafted poly-succinimide (PSI) (referred to as Polyaspartamide (PAA) adsorbent), was investigated.

Methyl Amine (MA) and Mono-Ethanol Amine (MEA) were employed as water-soluble amines and the effect of changes in their concentration on CO_2 adsorption capacity was investigated as well. Water-soluble amines were incorporated to allow water solubility of the adsorbent paving the way for freeze-drying to improve the geometric structure (surface area, pore volume and pore size) of the adsorbent. Initially, the PSI was loaded with Ethylenediamine (EDA), forming PSI-EDA. The water-soluble amines were grafted to PSI-EDA, with the EDA added to improve the chemical surface of the adsorbent for CO_2 capture.

NMR and FTIR analyses were performed and confirmed the presence of MA and MEA amine groups in the PAA, thereby indicating the presence of the grafted amines on the backbone polymer. BET analysis was performed and reported the pore volume, pore size and surface area of the freeze-dried material. It was observed that the physical properties did not change significantly after the freeze-drying compared to literature where freeze-drying was not employed. An increase in adsorption capacity with an increase in MA and MEA concentrations in MA-PAA and MEA-PAA samples was observed. At low amine concentrations (20% amine and 80% EDA grafted), MEA-PAA was observed to exhibit higher adsorption capacity compared to the MA-PAA samples. At high amine (100% amine grafted) concentrations, MA-PAA samples displayed higher adsorption capacity. Three runs were performed on each sample and the results obtained were reproducible. The best adsorption capacity obtained was 44.5 g CO_2/kg Ads.

Further work was then performed to understand the effects of operating variables on CO_2 adsorption as well as the interactive effect using the Response Surface Methodology approach. The experiments were done by use of CO_2 adsorption equipment attached to an ABB gas analyzer. A central composite design of experiment method with a total of 20 experiments was employed to investigate three factors, namely, temperature, pressure and gas flow rate. Six regression models were drawn up and mean error values computed by use of Matlab, followed by response surfaces as well as contours, showing the influence of the operating variables on the adsorption capacity as well as interaction of the factors were then drawn up.

The results obtained displayed that each of the factors investigated, temperature, pressure and gas flowrate had an incremental effect on the adsorption capacity of PAA, that is, as each factor was increased, the adsorption capacity increased up to a point where no more increase occurred. Adsorption was seen to increase for both an increase in gas flowrate and adsorption pressure to a maximum, thereafter it starts to decrease. A similar trend was observed for the interaction between temperature and pressure. However, the interaction between gas flowrate and temperature was such that, initially as the temperature and the gas flowrate increase, the adsorption capacity increases to a maximum, thereafter, the temperature seizes to have an effect on the adsorption capacity with a combined effect of decreasing temperature and increasing gas flowrate resulting in a further increase in adsorption capacity.

It was confirmed that the operating variables as well as the flow regime have an effect on the CO_2 adsorption capacity of the novel material. The highest adsorption capacity was obtained in the pressure range 0.5 bar to 1.7 bar coinciding with the temperature range of 10 ^oC to 45 ^oC. The interaction of gas flowrate and adsorption pressure was such that the highest adsorption capacity is in the range 0.8 bar to 1.5 bar which coincides with the gas flowrate range from 35 ml / min to 60 ml / min. In conclusion, the best adsorption capacity of 44.5 g / kg via the TGA and 70.4 g / kg via the CO_2 adsorption equipment was obtained from 100 % MA grafted PSI.