Abstract

Developing energy efficient carbon capture technologies is of great importance to combat climate change. Currently, the commercialization of adsorbent based capture technologies is hampered by both the size of equipment and the energy associated with the carbon abatement. The 3D-CAPS project aims to solve these challenges associated with removing and recovering CO₂ from industrial gases by significantly increasing the productivity (kg CO₂/m³ hr) of two adsorbent based technologies by structuring through 3D-printing: a) potassium-promoted hydrotalcite (K-HTC) for sorption-enhanced water-gas shift (SEWGS)¹ and b) amine functionalized silica (ImmoAmmo)².

Structured adsorbents and catalysts have recently gained significant interest owing to the advantages of lower pressure drop and faster mass transfer over conventional shaped materials³,⁴. The required adsorbents for these technologies are prepared using the latest innovations in additive manufacturing (3D-printing). This technology allows to prepare bespoke materials, with tailored channel sizes and wall thickness, having improved heat and mass-transfer characteristics, that are not available through traditional material preparation routes.

Development of 3D-printed microporous ceramic materials

The 3D-technology used to develop the structured adsorbents is Digital Light Processing (DLP; Figure 1). This technology consists of an indirect slurry-based process that uses a photo-active material to initiate binding. After printing the structure layer by layer by illuminating cross-sections of the design, a debinding and sintering step is required to obtain the final structured adsorbents. For the ImmoAmmo adsorbent, the silica support will be printed after which various amines are impregnated or grafted on the structured material.
Figure 1: Schematic representation of DLP technology. The printer (3) illuminates the paste (1) layer-by-layer as a projected cross-section (2). After each layer, the structure is moved up, and the layer of paste is restored. After printing, delamination (4) and sintering (5) lead to the final structured material.

Pastes for 3D printing are developed for both the K-HTC and ImmoAmmo sorbents. Several 3D-structures, designed with the aid of mathematical modelling (CFD), have been printed and post-processed (Figure 2). For the ImmoAmmo sorbents a recipe to graft amino silanes onto the 3D-structured silica support is developed. The resulting sorbent shows similar capacities to the grafted silica beads. Also the printed and post-processed K-HTC materials keep their original CO₂ capture capacity compared to the starting sorbents.

Figure 2: Examples of 3D-printed sorbents. a) 3D-printed silica based isoreticular foam (ImmoAmmo) b) several K-HTC monolith structures before sintering. c) K-HTC monoliths after sintering d) advanced monoliths K-HTC structure with zig-zag channels.

Testing and modelling of 3D-structured sorbents for carbon capture applications

The 3D printed adsorbents are evaluated against traditional packed bed of pellets in Pressure Swing Adsorption (PSA) and Vacuum PSA processes for CO₂ capture in Natural gas combined cycle (NGCC) and decarbonized H₂ production. The adsorption characteristics (equilibrium isotherms and kinetic parameters) for the relevant gaseous components (CO₂, N₂, H₂O) as well as pressure drop for different structures are measured. Single and multi-column models for the performance of the SEWGS and ImmoAmmo 3D-printed solution for the selected applications have been set up. The models are calibrated for operation at the high-flow rates to obtain high productivity rates, capture rate and efficient utility use.

The experimental data are used to validate the multi-cycle models that determine the potential of the structures for productivity increase.

Productivity increase with 3D-structured sorbents

The highest obtained productivity increase is an 8x increase for the 3D-structured sorbents compared to the traditional packed bed configurations. This illustrates the high potential of 3D-structured adsorbents for productivity improvement and thereby size reduction of the equipment for efficient carbon capture.
References:

Acknowledgements: The ACT 3D-CAPS project # 271503 has received funding from RVO (NL), RCN (NO), UEFISCDI (RO), and is co-funded by the CO2 Capture Project (CCP) and the European Commission under the Horizon 2020 programme ACT, Grant Agreement No 691712.

Keywords: 3D-printing; solid sorbents; CO₂ capture; SEWGS; amines; productivity increase; CFD modelling; multi-cycle modelling.