IEAGHG 8th Post Combustion Capture Conference

16th to 18th September 2025 Marseille, France

# Techno-Economic Analysis of Packed Bed and Structured Adsorbent for Direct Air Capture

Paul de Joannis[a,b,*], Christophe Castel[b], Mohamed Kanniche[a], Eric Favre[b], Olivier Authier[a]

*[a]EDF R&D, 6 quai Watier, 78000 Chatou, France*
*[b]Université de Lorraine, CNRS, LRGP, 1 rue Grandville, F-54000 Nancy, France*

**Abstract**

Climate change has become a critical issue in recent decades and is attributed to increased levels of greenhouse gases, particularly $CO_2$, in the atmosphere. Carbon dioxide removal (CDR) solutions, which remove $CO_2$ from the atmosphere and store it permanently, have recently gained interest in the pursuit of carbon neutrality. The advantages of CDR over post-combustion capture are that the capture site is decoupled from the emission site, without the need to adapt the process that emits $CO_2$, giving CDR a key role in the decarbonization of hard-to-abate sectors such as aviation, agriculture, and shipping. Among these CDR technologies, direct air capture (DAC) is developing rapidly and could represent a capture capacity of 1 $GtCO_2$/yr in 2050, based on the *Net-Zero Scenario* of the International Energy Agency. Today, development is mainly based on adsorption and absorption separation of $CO_2$ from other air components, but new separation techniques based on electrochemistry and membranes are also emerging.

For around a decade, direct air capture technologies using adsorption have been undergoing notable development, initially supported by advances from Climeworks in Switzerland and Global Thermostat in the USA. These processes offer advantages such as the absence of chemical solvents and chemical emissions into the atmosphere. They enable VTSA (Vacuum Swing Thermal Adsorption) process with regeneration of adsorption materials at a relatively low temperature (< 100°C), combined with a primary vacuum typically around a few hundred mbar to improve efficiency. Innovations in adsorption materials, including ion exchange resins or organometallic networks (MOFs), as well as in their configurations (packed bed or structured adsorbent, etc.), open up prospects for optimizing performance and gas-solid contact. Nevertheless, these processes face challenges, not least the sensitivity of adsorption materials to substances present in the air, such as humidity, which can affect their efficiency. In addition, packed beds face high pressure drop and fan work to process the air through the bed, and structured adsorbents are gaining interest by reducing the pressure drop. These factors underline the importance of further research to improve the robustness and efficiency of adsorption DAC processes.

EDF R&D and LRGP-CNRS Nancy are studying DAC adsorption processes to assess their performance and requirements (materials and energy), as well as the issues involved in scaling them up. To the best of our knowledge, no study addressed up to now a systematic sensitivity and techno-economic analysis (TEA) of packed bed vs monolith process for DAC, based on a rigorous set of multicomponent $CO_2$/$H_2O$ equilibrium data. The study investigates a series of dynamic S-VTSA (Steam assisted-VTSA)

* Corresponding author. Tel.: +33 7 70 31 39 08
*E-mail address:* paul.de-joannis-de-verclos@edf.fr

simulations via Aspen Adsorption, a commercial adsorption software tool, with Lewatit VP OC 1065 as a benchmark sorbent (Figure 1). Lewatit shows the interest to be a commercially available adsorbent with capacity performances close to amine functionalized sorbents, and with reported $CO_2$/$H_2O$ co-isotherms over a broad range of temperature. This offers the opportunity to quantitatively investigate the impact of humidity on both $CO_2$ adsorption and sorbent regeneration steps, together with the interplay of adsorbent geometry (packed bed vs monolith).

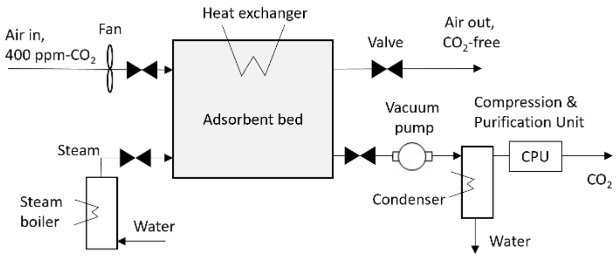


Figure 1 – Scheme of S-VTSA solid-based DAC.

The processes are evaluated at large capture scale (100 kt$CO_2$/yr) for $CO_2$ supercritical transport and geologic storage. The technical performance is evaluated in a reference case for two shaping of the sorbent: packed bed and monolith (Figure 2). The packed bed exhibits a higher productivity (2.4 kg$CO_2$/(h.m$^3$)) while the monolith achieves 1.2 kg$CO_2$/(h.m$^3$) but allows a large reduction of about 2 orders of magnitude in pressure drop and the associated fan work to push the air through the bed. Cost of capture is estimated by a unified methodology using the Aspen Process Economic Analyzer (APEA), a commercial software to perform early capital estimation from simulation data. Sensitivity on economic assumptions such as sorbent cost, design module cost, energy price, risks and contingencies, discount rate plant and learning rate is discussed. In order to evaluate the impact of the environmental and process parameters on the performance of solid-DAC, a sensitivity analysis is performed on design parameters (bed dimension, pellet radius, adsorbent coating thickness), operating conditions (air velocity, temperature and humidity, regeneration pressure and temperature) and system properties (adsorption/desorption loading and mass transfer coefficient). Detailed techno-economic analysis performed at capture scale of 100 kt$CO_2$/yr results in capture costs higher than 1500 €/t$CO_2$.

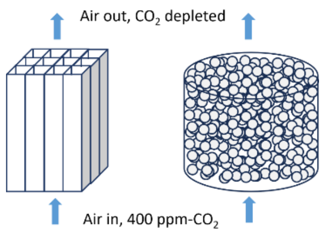


Figure 2 – Monolithic sorbent with squared channels (left) and packed bed (right).

*Keywords:* DAC; Direct Air Capture; Adsorption; Monolith; Lewatit VP OC 1065.