Rapid screening of carbon capture materials using small-scale 3D-printed fluidised beds

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- **Small-scale fluidised beds can play an important role in developing carbon capture materials**
- **Microfluidised beds must be operated in the bubbling regime to observe meaningful kinetic data**
- **Screening experiments last no more than 10 s in the TORBED reactor**

Introduction

A diverse portfolio of technologies, regulations, and frameworks will be needed to enable the global Net Zero emissions targets to be realised. Among these, carbon capture will likely play a major role in eliminating/offsetting greenhouse gas emissions whilst the shift to renewables and negative emissions initiatives occurs, at least in the short to medium timeframes. Adsorption-based processes are particularly appealing largely due to their high flexibility, non-volatility, and low energy burden for regeneration.

Ultimately, the success of adsorption-based processes depends on both the development of the materials (rapid kinetics, high capacity, high stability, high selectivity, *etc.*) and development of the corresponding gas-solid contacting technology (good mixing, low pressure drop, *etc.*). Here, we propose that small-scale fluidised beds can play an important role in the development of new CO_2 adsorbent materials/processes. Their small size is complementary with the early stages of materials development, where usually only small volumes of sample are synthesised since it would be inefficient to mass manufacture potentially poor performing materials before fully characterising them. Additional advantages include: low installation costs, good mixing/heat transfer, and low-energy consumption.

In this talk, we summarise the results of two ongoing projects that have used the small-scale fluidised bed platform for the screening of carbon capture materials:

1. Micro-Fluidised Bed Reactor

Here we screened the performance of an industrial hydrotalcite (Purol MG70, Sasol) using custom 3D-printed microfluidised beds with diameters of 10–15 mm.

In its raw state, this powdery material exhibited strong cohesive properties that initially prevented fluidisation. We therefore first studied the hydrodynamics by measuring the pressure drop to find suitable conditions for the kinetic screening experiments. We identified that a combination of pre-sieving the material to remove the fines (retaining sizes of >53 μm; 2 g/cm^3) and pre-fluidisation drastically improve the fluidisation quality **[1]**. This involved removing the strong hysteresis effect when increasing and decreasing the gas flow rate, reducing the magnitude of the pressure drop overshoot prior to fluidisation, and prevention of gas bypassing.

Subsequent CO_2 breakthrough experiments were performed for a range of configurations, including bed diameter/depth, gas flow rate, CO_2 concentration (8–16 vol%), and temperature (25–60 °C). We found that the maximum capacity of 0.78 ± 0.03 mmol/g measured in our fluidised beds occurred in the bubbling regime. The capacity decreased outside of this window due to either poor gas-solid mixing at low flow rates, or gas bypassing due to slugging at high flow rates. The maximum capacities measured in the microfluidised beds at each temperature matched independent TGA measurements, demonstrating that these beds can be reliably used to screen the kinetics of small samples of material provided that appropriate operating conditions are used.

2. Toroidal Fluidised Bed (TORBED) Reactor

Here we screened the performance of a branched PEI commercial adsorbent (from RTI International) using a novel small-scale toroidal fluidised bed reactor developed in our lab in collaboration with Torftech **[2]**.

The TORBED uses inclined blades to produce a swirling gas stream that enables significant intensification of the heat and mass transfer compared to 'conventional' fluidised beds without detriment to particle entrainment, particle attrition, and pressure drop.

CO_2 breakthrough experiments were performed for a range of CO_2 concentrations (2–20 vol%), bed loadings (1–2.5 g), gas flow rates (20–35 L/min), and temperatures (40–70 °C) **[3]**. The TORBED operates with a shallow rapidly-swirling annulus that enables the entire bed to simultaneously capture CO_2 from the fluidising gas. Screening experiments subsequently lasted for no more than 10 s, but with high capacities of up to 2.64 ± 0.06 mmol/g still being observable. These high capacities matched the expectations of the sorbent supplier, confirming that meaningful measurements can be obtained for such short residence times. Through measurement of the temperature inside the reactor during these breakthrough experiments, we also infer that the high heat transfer rates minimises the effect of the heat of adsorption on the measured kinetics.

Conclusions

In our microfluidised bed platforms, we can precisely study the capacity and kinetics as a function of CO_2 concentration and temperature, validated by independent TGA. In our TORBED platform, we can rapidly screen the adsorbent behaviour in experiments that last seconds. Both platforms also theoretically provide data on mechanical stability of the sorbent via measurement of the PSD before and after the experiments. Therefore, small-scale 3D-printed fluidised beds enable the screening of carbon capture materials under 'real-World' conditions, providing clarity for decision making and design beyond that available with fixed bed techniques.

Financial support from the Saudi Arabian Cultural Bureau in the UK and Newcastle University Overseas Research Scholarships (NUORS) are gratefully acknowledged. Additional thanks to Torftech Ltd. for advice on the design and operation of the 3D-printed TORBED reactor, and RTI International & Sasol for supplying adsorbent samples for testing.

References

[1] Alamri A., McDonough J., Zivkovic Z. Fluidisation behaviour and wall effects of cohesive hydrotalcite powder in a micro-fluidised bed. Powder Technology **415** (2023) 118192

[2] McDonough J.R., Law R., Reay D.A., Groszek D., Zivkovic V. Miniaturisation of the toroidal fluidisation concept using 3D printing. Chemical Engineering Research and Design **160** (2020) 129-140

[3] Jamei R., McDonough J.R., Reay D.A., Zivkovic V. Rapid and intensified screening of a carbon capture adsorbent using a 3D-printed swirling fluidised bed. Chemical Engineering Journal **451** (2023) 138405