Svante

Pilot-scale Demonstration of a Laminate-Based CALF-20 Rapid Cycle Pressure-Vacuum Swing Adsorption Process for Carbon Capture

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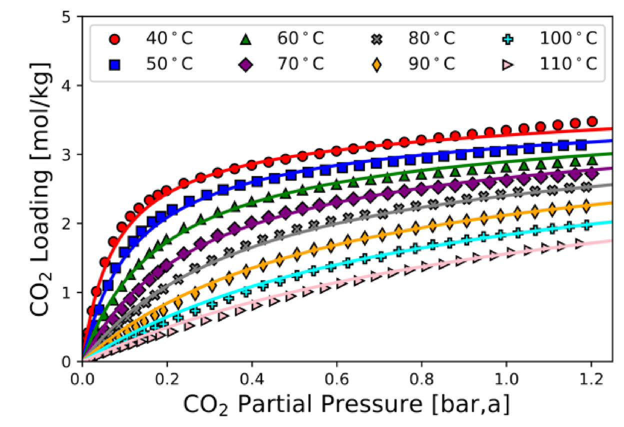
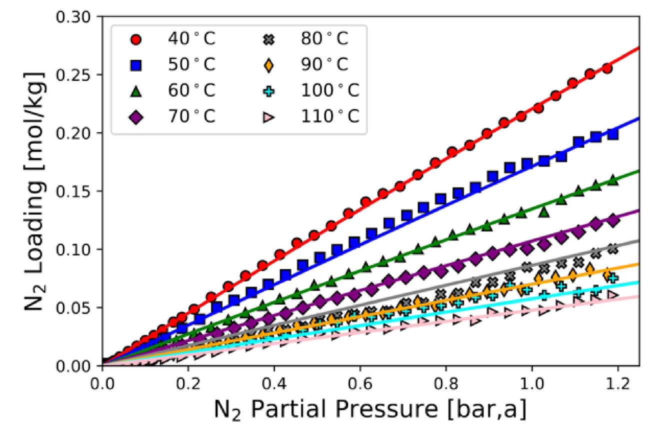
Introduction

Pressure-Vacuum Swing Adsorption as a Possible Solution to Small-Scale Emission Sources

- Adsorptive processes are a low-energy carbon capture separation alternative to liquid-amine processes
- Svante utilizes the Rapid Cycle Temperature Swing Adsorption (RCTSA) process[1], a temperature-concentration swing adsorption process using CALF-20[2,3] (a steam stable metal-organic framework) for point source capture
- Pressure-vacuum swing adsorption (PVSA) is not viable for large-scale operation (unlike RCTSA) due to the large plant footprint required[4]. However, several smaller-scale CO_2 emitters/processes may be good PVSA candidates
- This study aims to evaluate the benefits of structured laminate adsorbent beds (over packed-beds) in smaller-scale (≈<100 tpd) rapid cycle PVSA processes
- Unary adsorption equilibrium data for CO_2 and N_2 on CALF-20 is favorable for both RCTSA and PVSA processes

CALF-20 Powder Isotherms



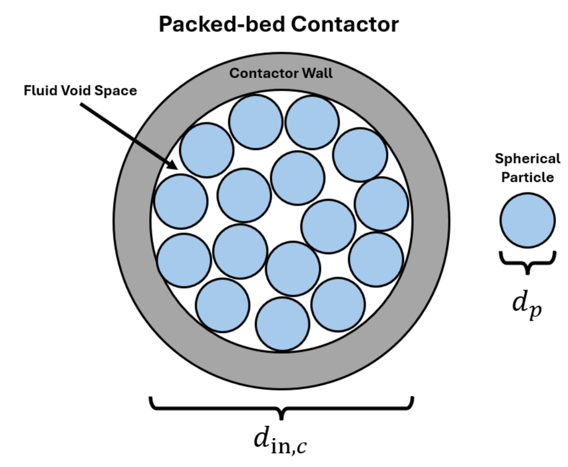


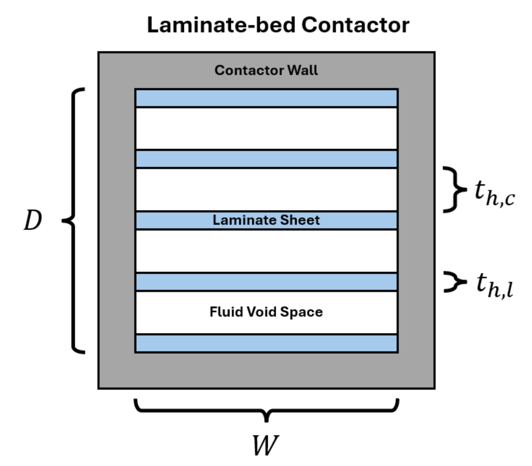
Objectives: Demonstrate laminate-bed capability in PVSA processes & determine where it may outperform the packed-bed contactor

Laminate- & Packed-Bed Contactors

Geometry of the Two Contactors

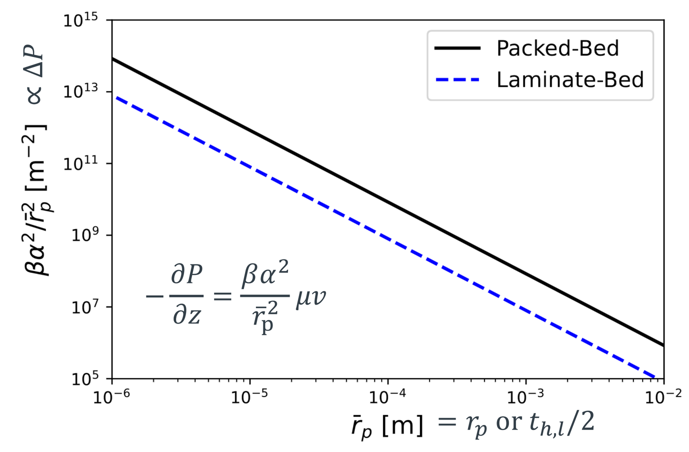
- Considered a packed-bed in a cylindrical column and a laminate-bed in a square column[3]
- Packed-bed has a bed voidage (ϵ) of 0.4 & the laminate-bed has ϵ = 0.5[3]
- Characteristic radiuses ($\bar{r}_p$) of the contactors are: particle radius (r_p) & half laminate thickness ($t_{h,l}/2$)





Pressure-Drop (fixed v)

- The estimated pressure-drop $\left(\frac{\partial P}{\partial z}\right)$ of the two contactor types always favors the laminate bed (at fixed characteristic radius, $\bar{r}_p$)
- $\beta\alpha^2$ is unique for each contactor type: $\frac{150}{4}\left(\frac{1-\epsilon}{\epsilon}\right)^2$ & $\frac{32}{4}$ for the packed-bed and the laminate-bed, respectively
- This allows the laminate-bed to operate at higher interstitial velocities while experiencing an equivalent pressure-drop to the packed-bed



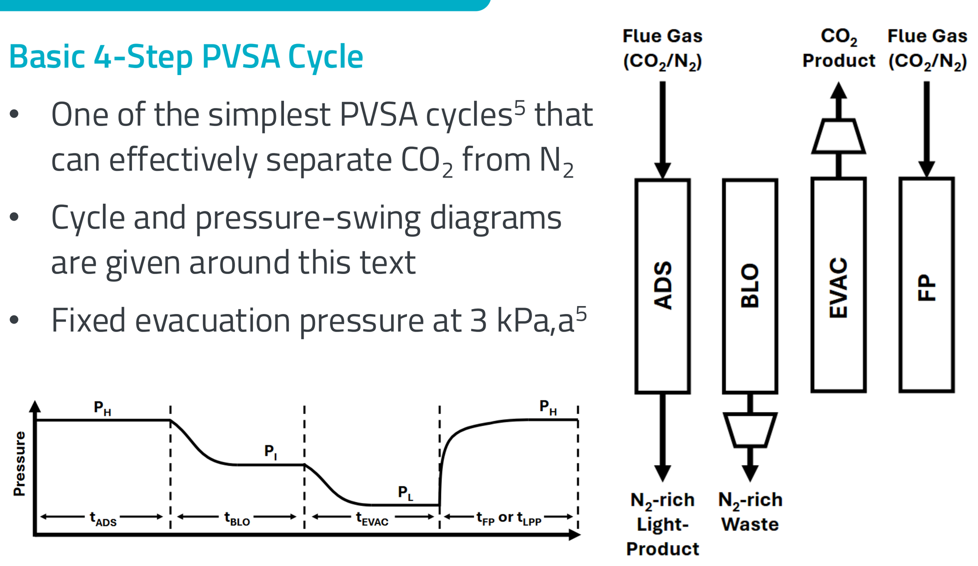
Laminate-Bed Process Experiments

Overview

- Process experiments at a varied inlet composition (8, 12, 16 mol% CO_2 in N_2), adsorption pressure, blowdown pressure, inlet flowrate, and cycle step times were performed to determine optimal laminate-bed process performance
- Laminate-beds perform as expected
- Multiple parametric studies done to show observed/expected trends

Basic 4-Step PVSA Cycle

- One of the simplest PVSA cycles[5] that can effectively separate CO_2 from N_2
- Cycle and pressure-swing diagrams are given around this text
- Fixed evacuation pressure at 3 kPa,a[5]



Experimental Optimization Results

- Best performing operation is summarized in the table to the right (all feed compositions)
- Higher inlet y_{CO_2} promoted ↑ Rec & ↑ Pr
- Optimal Pr found at t_{cycle} ≈ 80-90 s
- Allowable productivity is ≈1.9x greater than what is reported in the literature[6] (≈ 2.4 tpd m^{-3} at 15 mol%)

Optimal Results for all Feed Compositions

y_{CO_2} [mol%]	Pu [mol%]	Rec [%]	Pr [tpd m^{-3}]
16	94.9	72.8	4.65
12	94.6	65.6	3.45
8	95.2	55.0	1.89

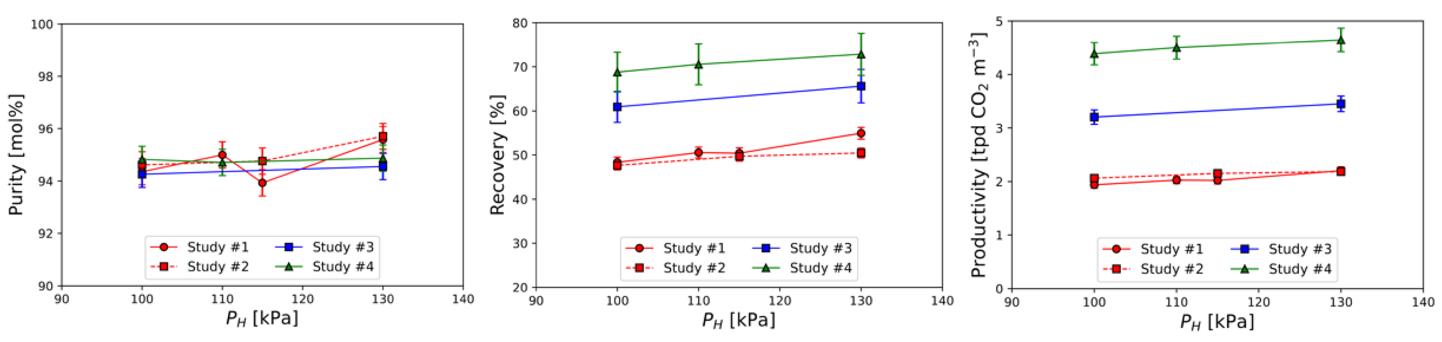
Pu = Purity, Rec = Recovery, Pr = Productivity

Experimental Parametric Study

- Several experiments were for a similar set of operating conditions with one operating parameter changed
- Parametric study summarized below with their effects on process performance (Pu, Rec, Pr)
- 8, 12, and 16 mol% CO_2 feeds are denoted by: red, blue and green markers, respectively

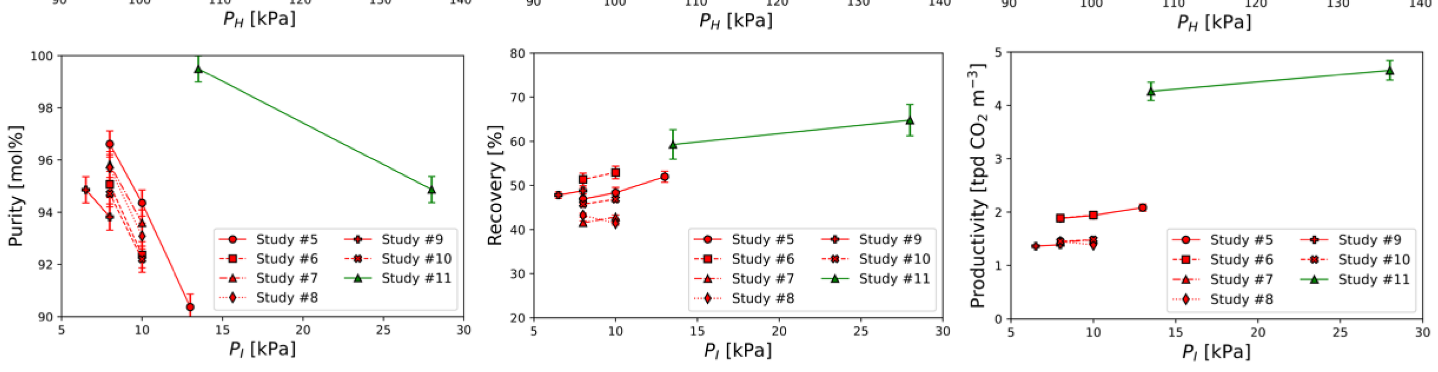
Adsorption Pressure

as P_H ↑: Pu ↑, Rec ↑, Pr ↑



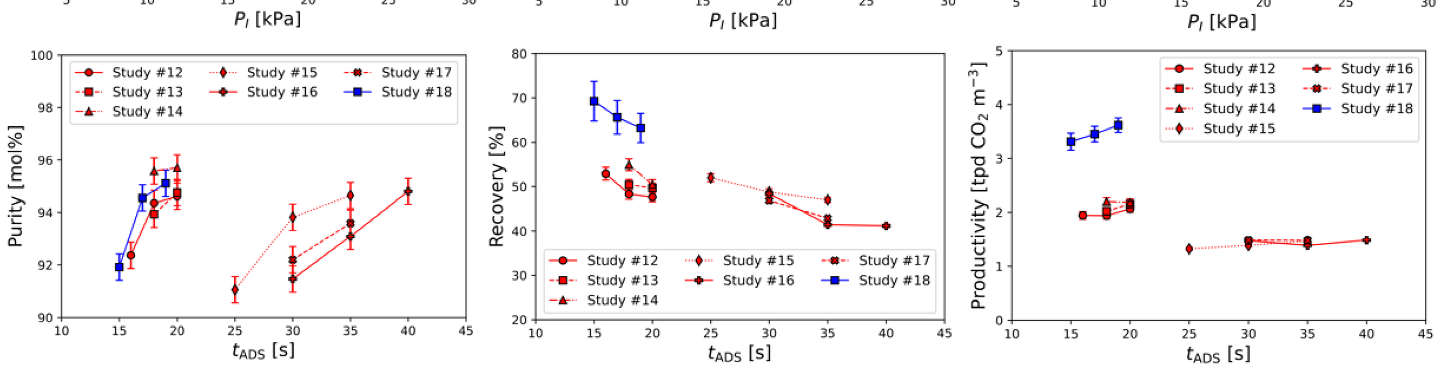
Blowdown Pressure

as P_I ↑: Pu ↓, Rec ↑, Pr ↑



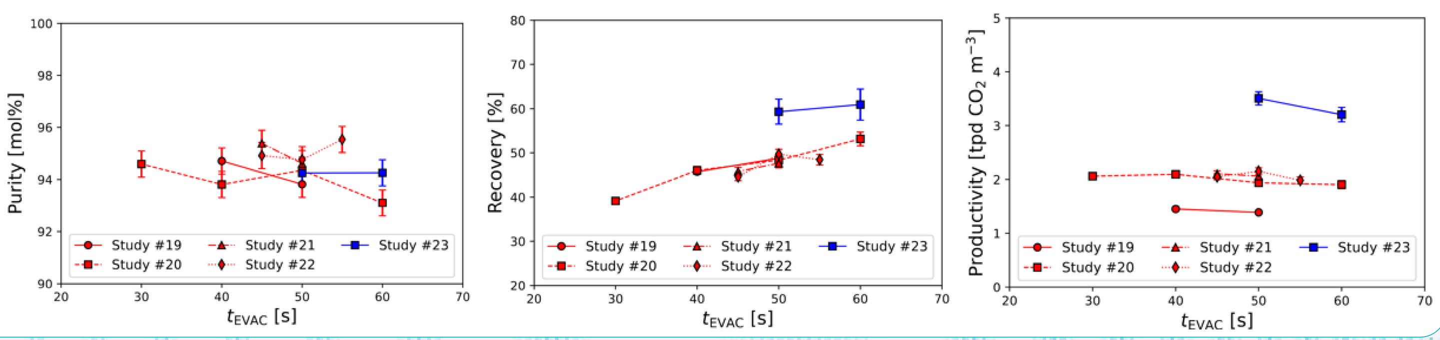
Adsorption Step Time

as t_{ADS} ↑: Pu ↑, Rec ↓, Pr ↑ or constant



Evacuation Step Time

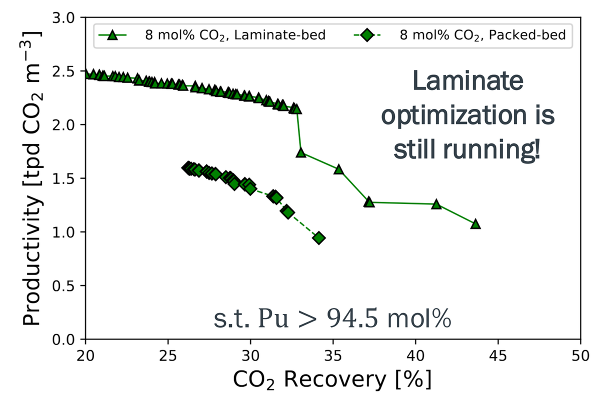
as t_{EVAC} ↑: Pu inconclusive, Rec ↑, Pr ↓ or constant

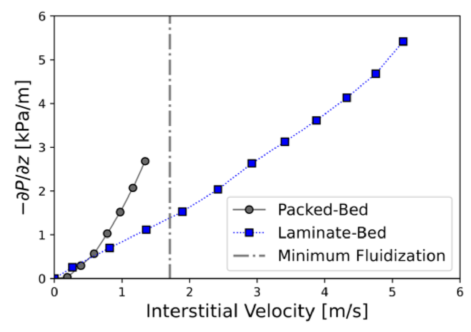


Comparison of Laminate- & Packed-Bed Experiments

Overview

This section details the comparison of two equivalent contactors (laminate-bed & packed-bed) manufactured at Svante. Both are 1.0 m tall and are ≈ 4 cm in diameter. Experimental and numerical tests were conducted & discussed below.



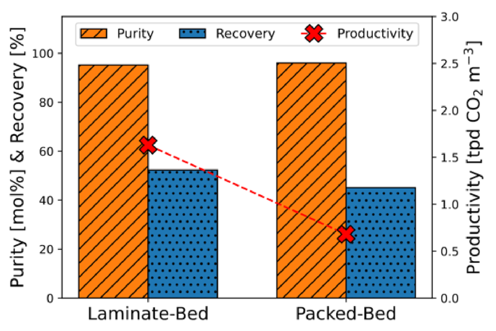


Pressure-Drop Comparison

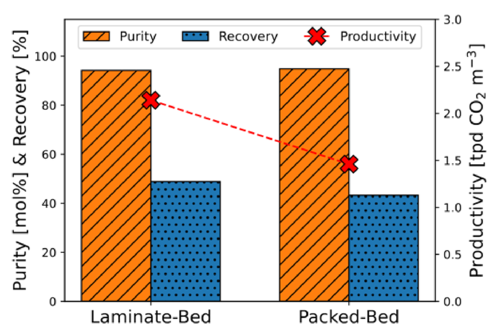
- Packed-bed & laminate-bed pressure-drops measured
- Laminate bed has a much lower resistance to flow & can reach much larger velocities

Process Performance at an Across an Equivalent Pressure-Swing

- Experimental process tests run for: P_H = 101 kPa,a, P_L = 3 kPa,a, and P_I = to either 6 (left) or 8 (right) kPa,a
- Pu was similar, laminate Rec & Pr were > than the packed-bed



P_I = 6 kPa,a



P_I = 8 kPa,a

Overall Process Results

Both experimental and numerical process optimizations were performed. Key findings:

- Pu is the same for both contactors
- Rec is > for the laminate-bed than the packed-bed by approximately 5% (also observed in simulations)
- Pr is > for the laminate-bed than the packed-bed
- Pr is > in numerical simulations (above) by at least ≈ 1.5-2.0x (preliminary: optimizations still running)

Optimal Experimental Results for P_H = 101 kPa,a

Contactor	y_{CO_2} [mol%]	Pu [mol%]	Rec [%]	Pr [tpd m^{-3}]
Laminate	8	95.7	48.0	2.16
Packed	8	94.8	43.4	1.46

Conclusions

This work presented a pilot-scale demonstration of a rapid-cycle PVSA carbon capture process using a CALF-20 laminate-bed contactor. This process is proposed for smaller-scale CO_2 emitters (<100 tpd CO_2) as PVSA is not suitable for large-scale (point-source) processes; we recommend the RCTSA process for large scale operation. Its performance was compared with an equivalent packed-bed. Both contactors were manufactured at Svante Technologies Inc. in Burnaby (BC), Canada. Key findings are summarized below:

- A theoretical study using literature correlations was performed to determine which regions produced better pressure-drop for the laminate-bed and the packed-bed. The laminate-bed always had a lower pressure-drop at a shared $\bar{r}_p$.
- 8, 12, and 16 mol% CO_2 feeds (dry, balance N_2) were optimized experimentally for the laminate-bed in the basic 4-step cycle. Optimal performance was detailed in the table to the left. Higher compositions performed better than lower compositions in allowable recovery and productivity (at a fixed purity). Different parameter operations were highlighted.
- Equivalent dimension contactors were tested experimentally for both the packed and laminate-beds. The laminate-bed offered a better pressure-drop and could produce better recoveries and productivities (up to 1.9x better) than the packed-bed. This was validated with numerical optimizations and packed-bed results in the literature[6].

The next steps of this study are to: study advanced cycles under humid conditions using CALF-20 laminate contactors.

Acknowledgements & References

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1. Rezaei, Sabereh, Andrew Liu, and Pierre Hovington. "Emerging technologies in post-combustion carbon dioxide capture & removal." Catalysis Today (2023): 11428
2. Lin, Jian-Bin, et al. "A scalable metal-organic framework as a durable physisorbent for carbon dioxide capture." Science 374.6574 (2021): 1464-1469.
3. Peh, Shing Bo, et al. "Direct contact TSA cycle based on a hydrophobic MOF sorbent for post-combustion CO_2 capture from wet flue gas." Chemical Engineering Science 301 (2025): 120744.
4. Subraveti Gokul, et al. How much can novel solid sorbents reduce the cost of post-combustion CO_2 capture? A techno-economic investigation on the cost limits of pressure–vacuum swing adsorption. Applied Energy. 2022 Jan 15;306:117955.
5. Haghpanah, Reza, et al. "Cycle synthesis and optimization of a VSA process for postcombustion CO_2 capture." AIChE Journal 59.12 (2013): 4735-4748.
6. Nguyen, Tai T. T., George K. H. Shimizu, and Arvind Rajendran. "CO_2/N_2 separation by vacuum swing adsorption using a metal–organic framework, CALF-20: Multi-objective optimization and experimental validation." Chemical Engineering Journal 452 (2023): 139550.

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