Adsorbent Screening for novel Swing Adsorption Reactor Cluster (SARC) in Post Combustion CO_2 Capture

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Swing Adsorption Reactor Cluster (SARC) for post combustion CO_2 capture

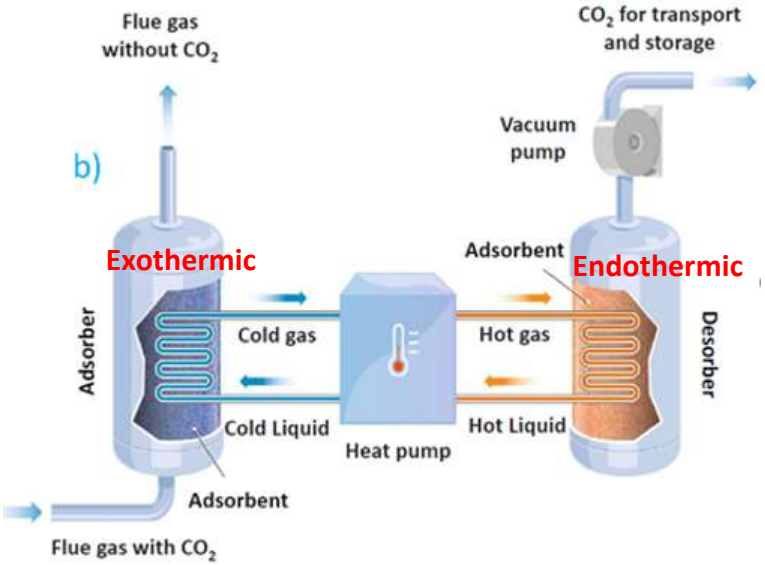
What?

Working principle

- A low temperature adsorption based CO_2 capture
- Lower energy penalty by:
  - Combining vacuum and temperature swings for sorbent regeneration
  - Heat integration between the stages using a heat pump

Main advantages

- It only needs electricity
  - Easy retrofitting to existing plants
  - It can benefits for future electrification of industrial sector



SARC conceptual design

*Zaabout, A., M. C. Romano, S. Cloete, A. Giuffrida, J. Morud, P. Chiesa and S. Amini (2017). International Journal of Greenhouse Gas Control **60**: 74-92.*

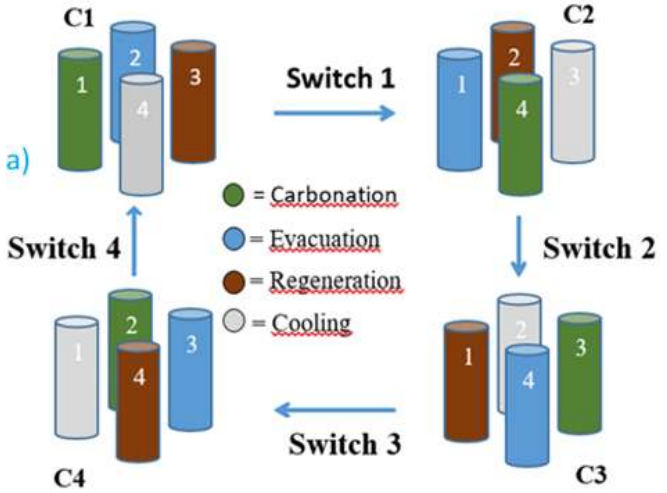
SARC cycle for capturing CO_2

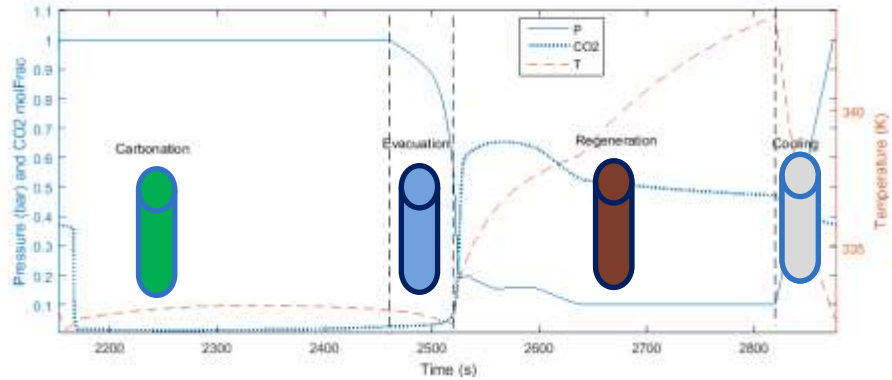
SARC uses a cluster of fluidized bed reactors each reactor cycles the four following stages:

- Carbonation: capturing CO_2 from the flue gas
  - Low temperature and atmospheric pressure pressure
- Evacuation: to control CO_2 purity
  - The pressure is decreased at constant temperature
- Regeneration: to release CO_2 from the sorbent
  - The pressure is further decreased and the temperature is increased
- Cooling:
  - the temperature and pressure are brought back to the initial conditions for starting a new cycle

$$Am(s) + CO_2(g) \leftrightarrow AmCO_2(s)(\Delta H = 75\,kJ\,mol^{-1}) \quad (1)$$

$$H_2O(g) \leftrightarrow H_2O(s)(\Delta H = 43\,kJ\,mol^{-1}) \quad (2)$$



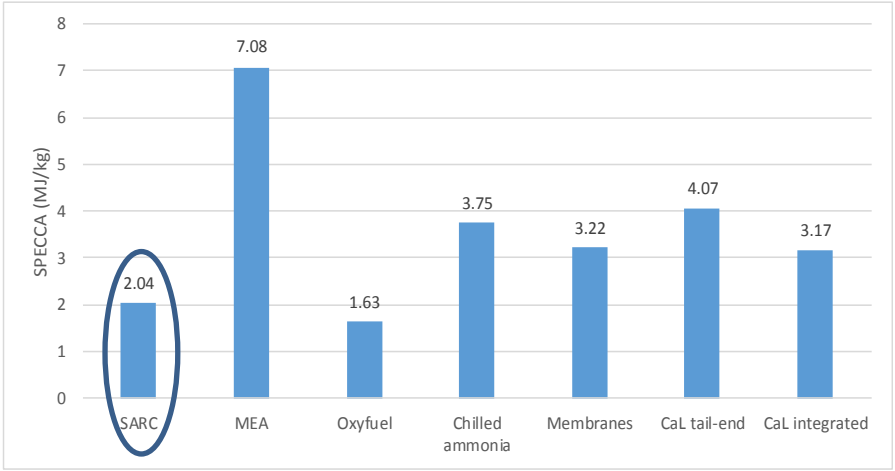


SARC operation phases (0D SARC model)

SARC technology

Why?

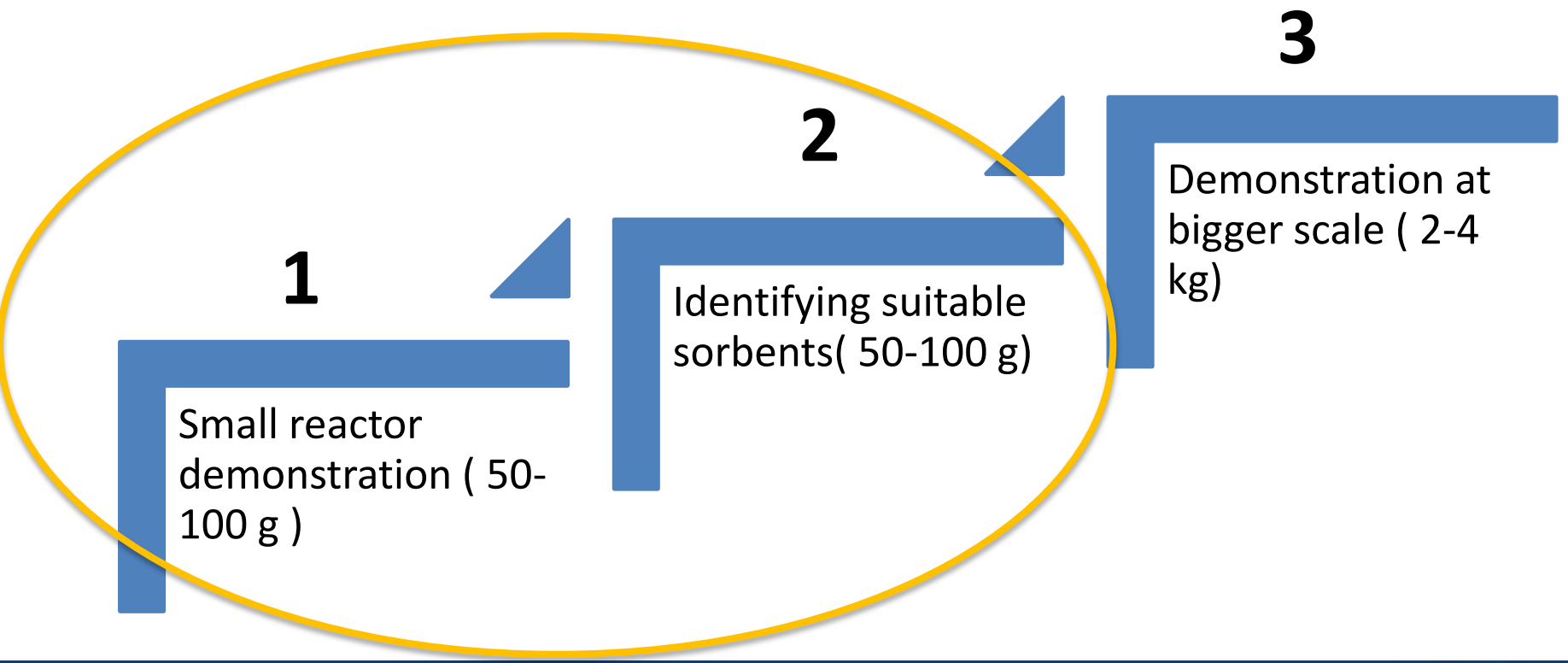
- SARC has a very competitive energy penalty
- Lower SPECCA could be achieved if renewable electricity is used
- Easy retrofitting to existing plants



SPECCA: specific primary energy consumption per avoided CO_2 for the different CO_2 capture technologies

*Cloete, S., A. Giuffrida, M. C. Romano and A. Zaabout (2019). Journal of Cleaner Production **223**: 692-703.*

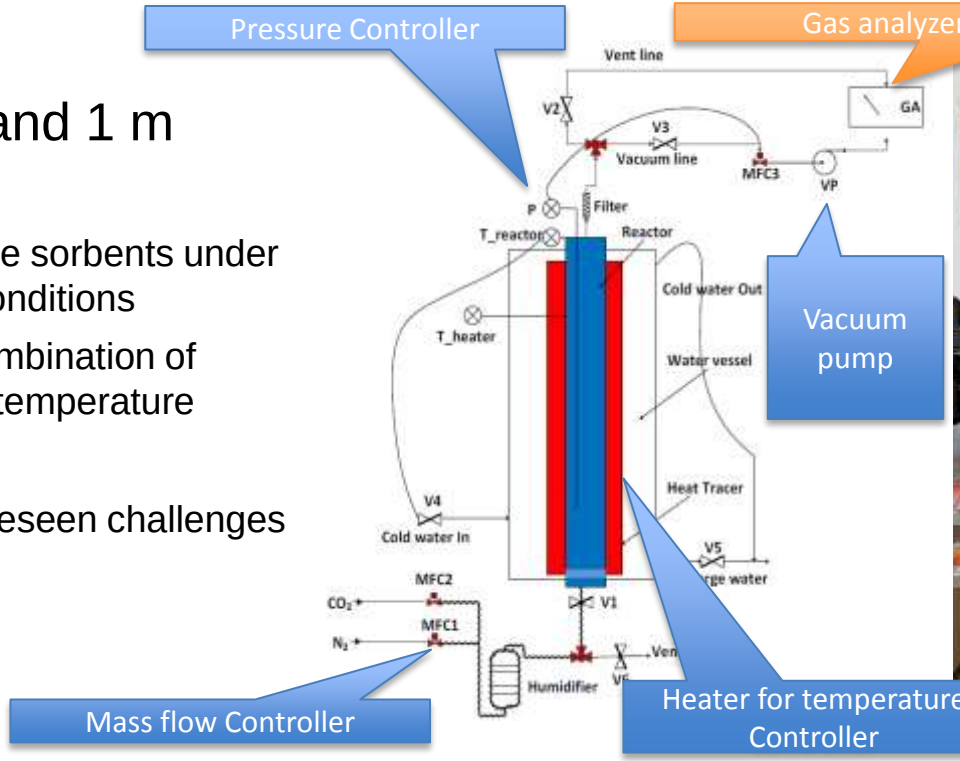
Experiment demonstration approach



First proof of technical feasibility

A 2 cm reactor and 1 m length for:

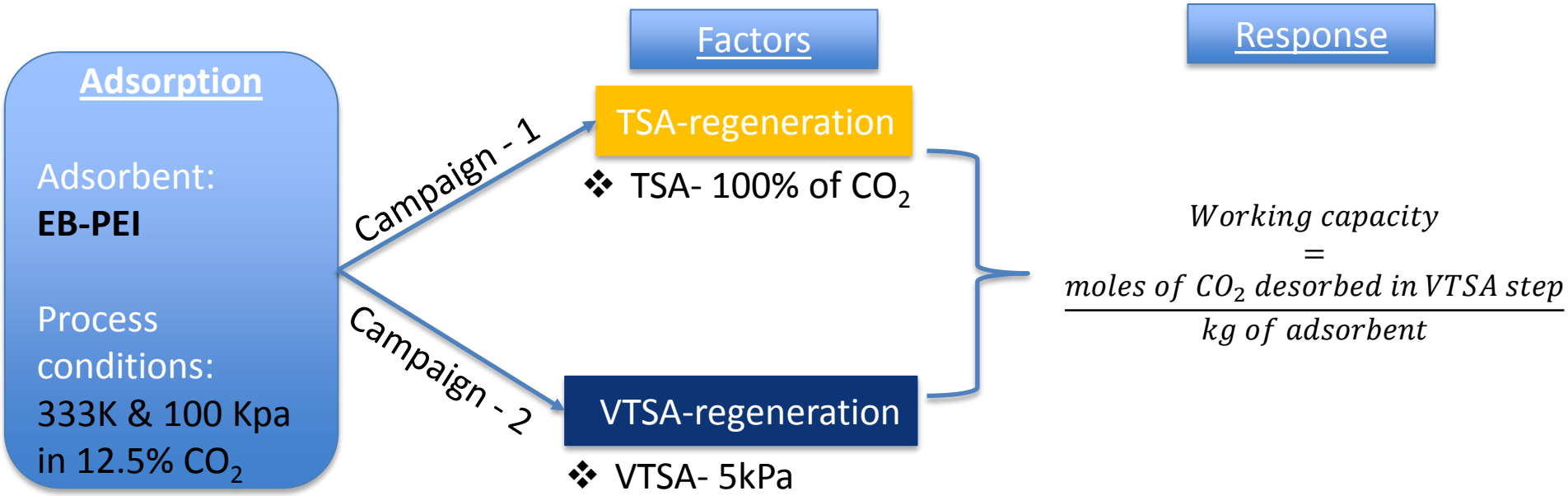
- Screening the sorbents under real SARC conditions
- Practicing combination of vacuum and temperature swings
- Identify unforeseen challenges



Simplistic experimental set up

Dhoke, C., et al. Chemical Engineering Journal, 2018.

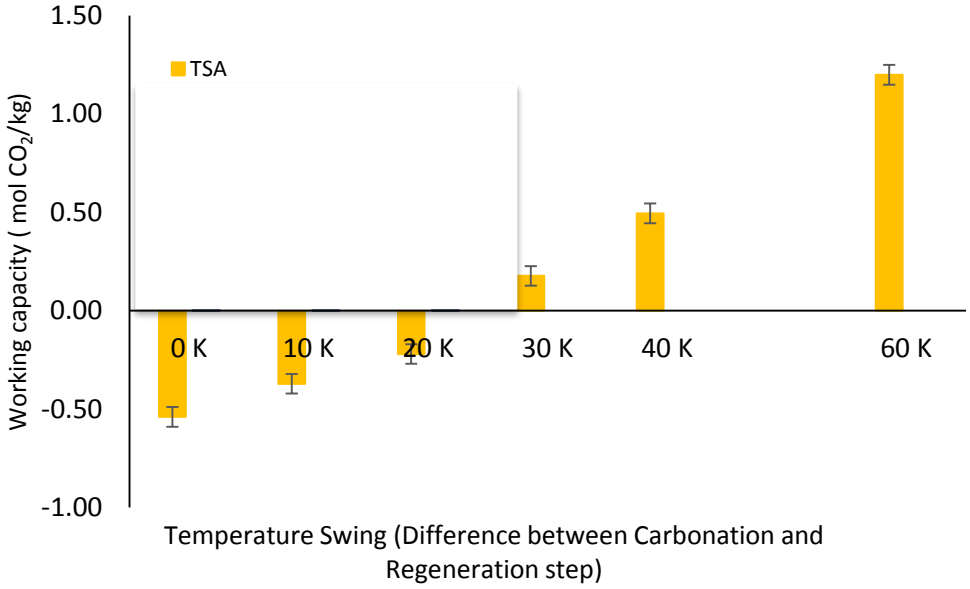
Study 01- Comparative Study (TSA vs. VTSA)



EB-PEI : 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO_2 sorbent supplied by KRICT

Dhoke, C., et al., *The swing adsorption reactor cluster (SARC) for post combustion CO_2 capture: Experimental proof-of-principle.* Chemical Engineering Journal, 2018 (In press)

Study 01 - Comparative Study (TSA vs. VTSA)



VTSA reduce the required temperature swing by 30-40 K relative to TSA for achieving a given working capacity.

- Adsorbent: Polyethyleneimine (EB-PEI)-KRICT
- Adsorption 333K & 100 Kpa in 12.5% CO_2
- Regeneration: VTSA- 5kPa
- Regeneration: TSA- 100% of CO_2

TSA: Temperature swing adsorption
VTSA: Vacuum combined with temperature swing

Dhoke, C., et al., *The swing adsorption reactor cluster (SARC) for post combustion CO_2 capture: Experimental proof-of-principle.* Chemical Engineering Journal, 2018 (In press)

Study 02-Sorbents Screening

Sorbents

- EB-PEI
- PEI-MOF
- K/ZrO_2
- Na/ZrO_2

Factors

Levels	Pressure (kPa)	Temperature swing (K)
I	5	0
II	10	10
III	15	20 -60

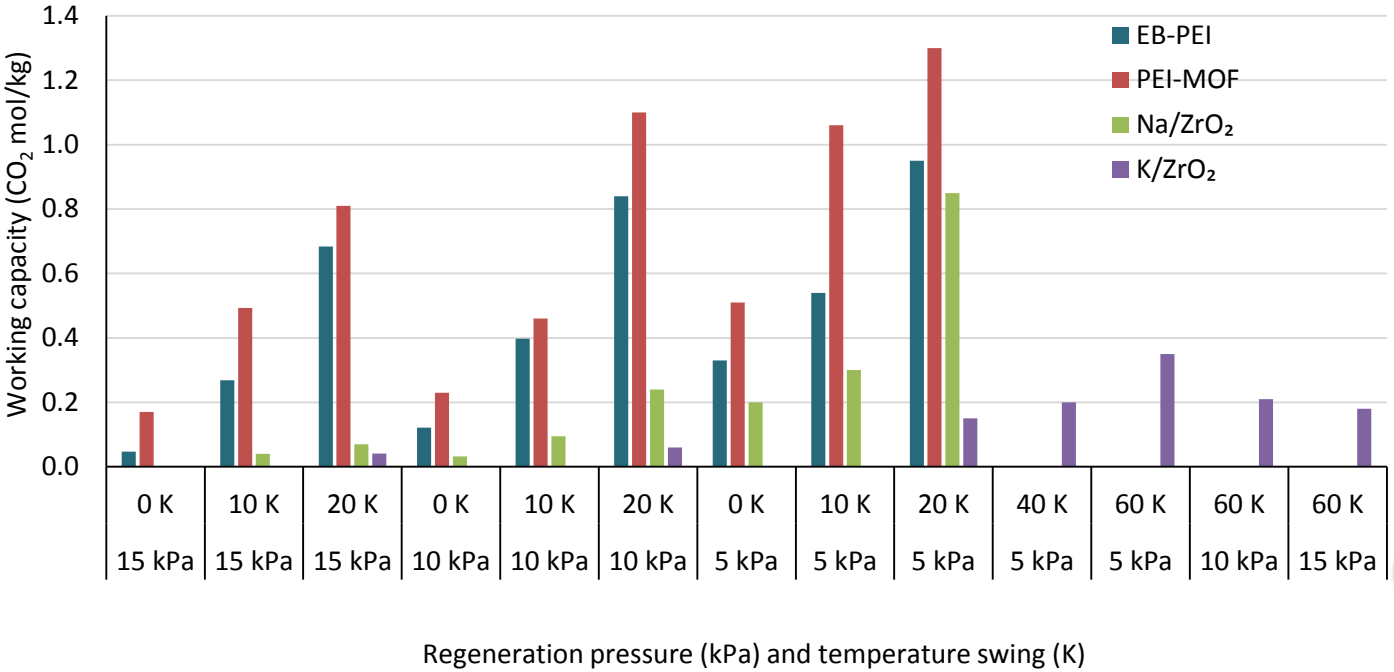
Response

$$Working\ capacity = \frac{moles\ of\ CO_2\ desorbed\ in\ VTSA\ step}{kg\ of\ adsorbent}$$

EB-PEI : 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO_2 sorbent supplied by KRICT
PEI-MOF: Polyethyleneimine and Metal organic framework supported on SiO_2 developed at RTI
K/ZrO_2 : Potassium sorbent supported on ZrO_2 (K/ZrO_2) supplied by KRICT
Na/ZrO_2 : Sodium sorbent supported on ZrO_2 (Na/ZrO_2) supplied by KRICT

Submitted to Chemical Engineering Journal (CEJ-D-19-06367)

Study 02- Screening of sorbent-VTSA



- Sorbent screening in a 2 cm reactor
- Polyethyleneimine (PEI) sorbents proved to be the best

Submitted to Chemical Engineering Journal (CEJ-D-19-06367)

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Study 03- Effect of steam

Sorbents

- EB-PEI
- PEI-MOF

Factors

Levels	H_20 (mole %)
I	0 %
II	5 %

VTSA-10 kPa and 20 K

Response

$$Working\ capacity = \frac{moles\ of\ CO_2\ desorbed\ in\ VTSA\ step}{kg\ of\ adsorbent}$$

EB-PEI : 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO_2 sorbent supplied by KRICT

PEI-MOF: Polyethyleneimine and Metal organic framework supported on SiO_2 developed at RTI

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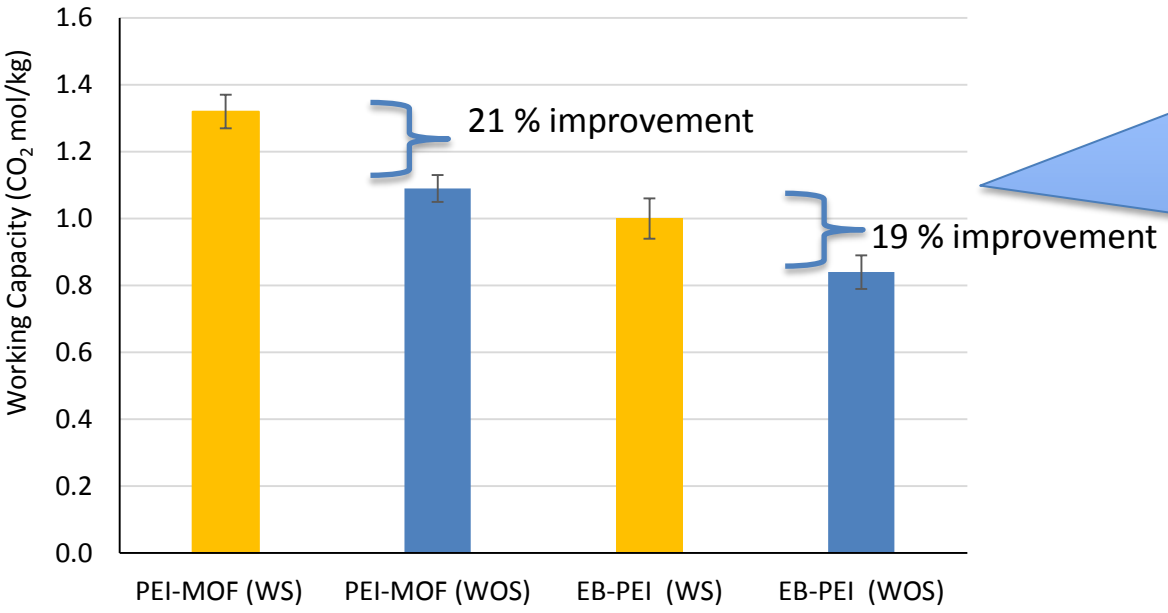
Effect of steam on VTSA- 100 mbar & 20 C



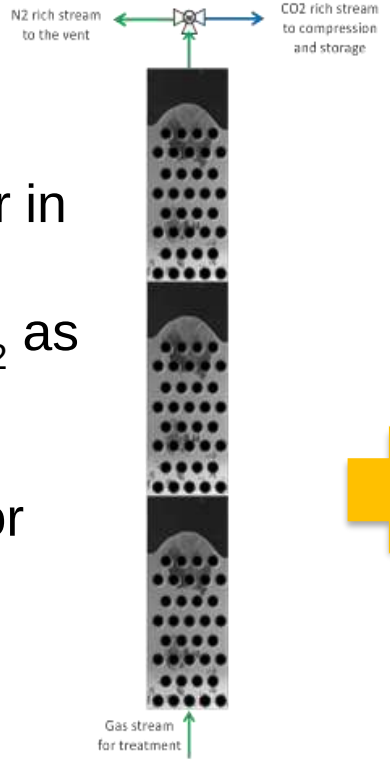
- Increase in the working capacity by the addition of the H_2O for both PEI sorbents
- Dilution of CO_2 by the desorption of water enables good desorption driving force

*WS- with 5 mole % water *WOS- without water

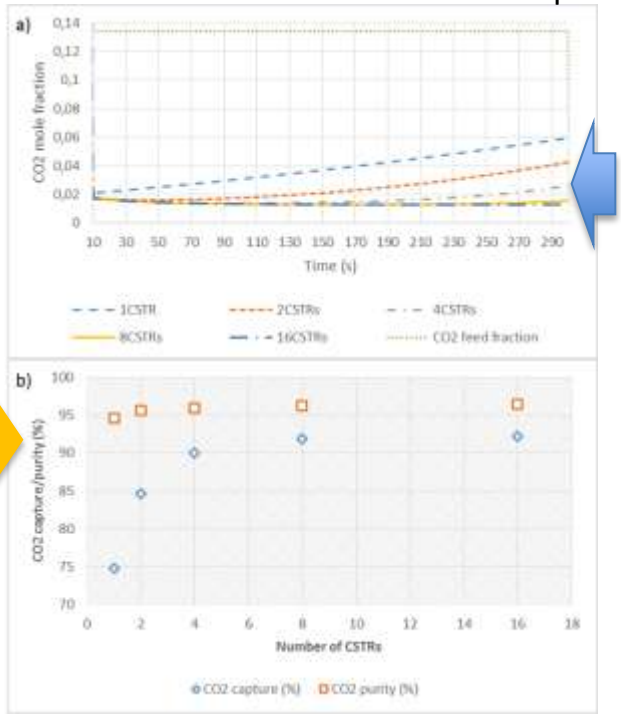
Submitted to Chemical Engineering Journal (CEJ-D-19-06367)

SARC- multistage fluidized bed

- Multistage fluidized bed
- Achieve more plug flow behaviour in the reactor
  - Flue gas with decreasing P_{CO_2} as it rises should meet fresher sorbent
- Maintain high heat transfer rate for heat recovery or addition



Transient CO_2 mole fraction at the reactor outlet in the carbonation step



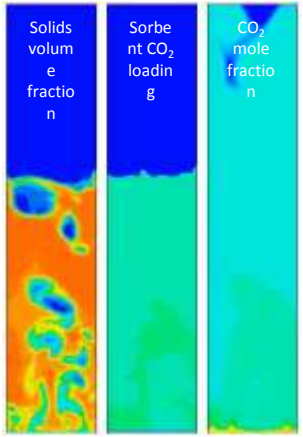
overall CO_2 capture efficiency and purity

Zaabout, A., M. C. Romano, S. Cloete, A. Giuffrida, J. Morud, P. Chiesa and S. Amini (2017). "Thermodynamic assessment of the swing adsorption reactor cluster (SARC) concept for post-combustion CO2 capture." International Journal of Greenhouse Gas Control **60**: 74-92.

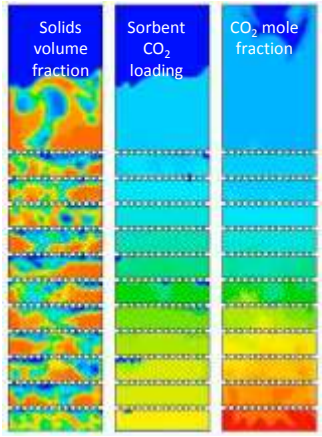
Reactor design

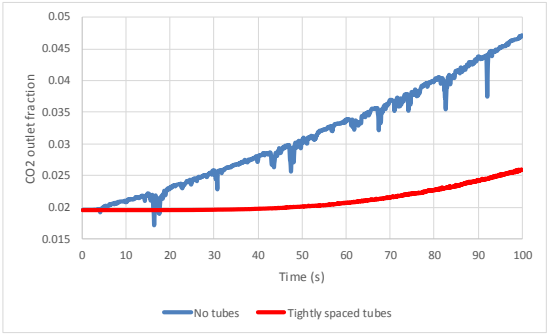
- Reactor design was investigated using CFD simulations
- Horizontal rows of narrowly spaced tubes were required to restrict axial back-mixing
- Such a more segregated solids CO_2 loading profile ensures higher CO_2 capture
- This behavior could be simply reproduced by a single narrow tube, which was recommended for the first experimental campaign

Reactor without tubes



Reactor with tubes

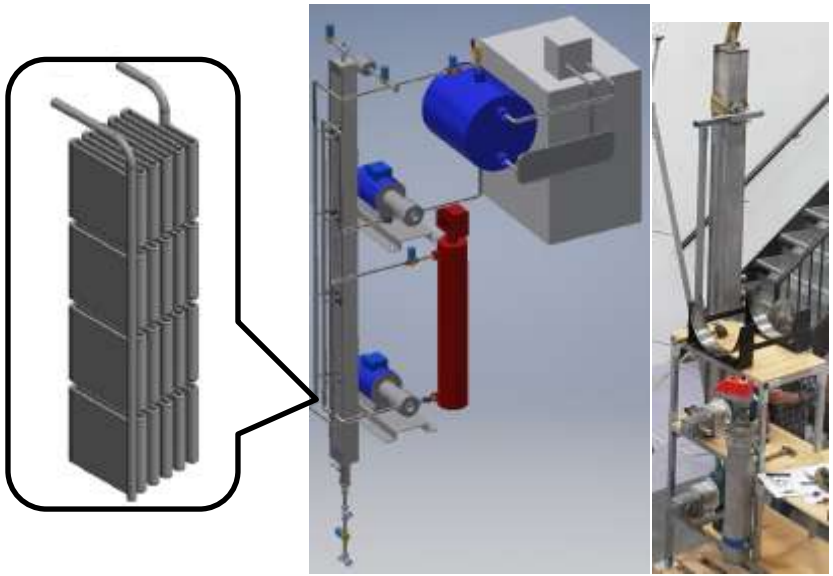




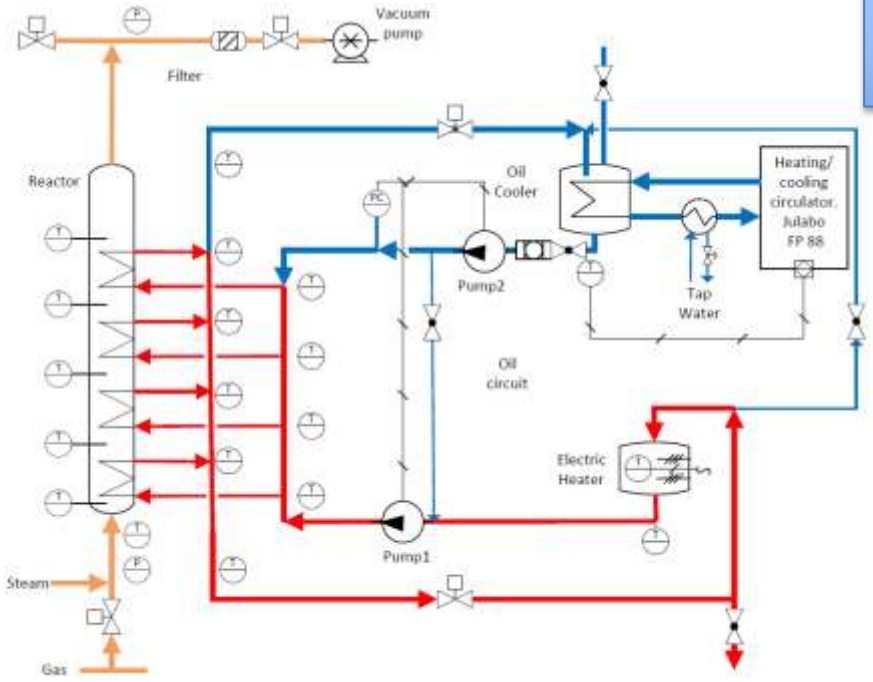
CO_2 mole fraction in the reactor outlet

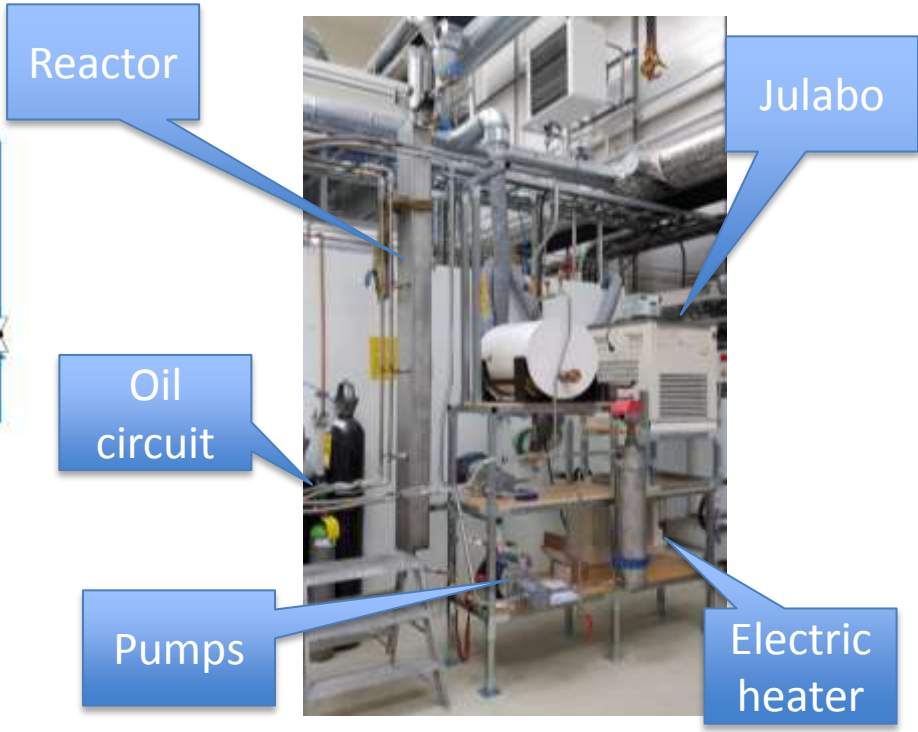
Demonstration of SARC concept in a multistage reactor with embedded heat transfer surfaces

- A four-stages reactor (10 cm ID and 200 cm height)
- Integrated heat transfer surfaces for temperature swing
- A vacuum pump is used for the vacuum swing



SARC- Big reactor





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Summary

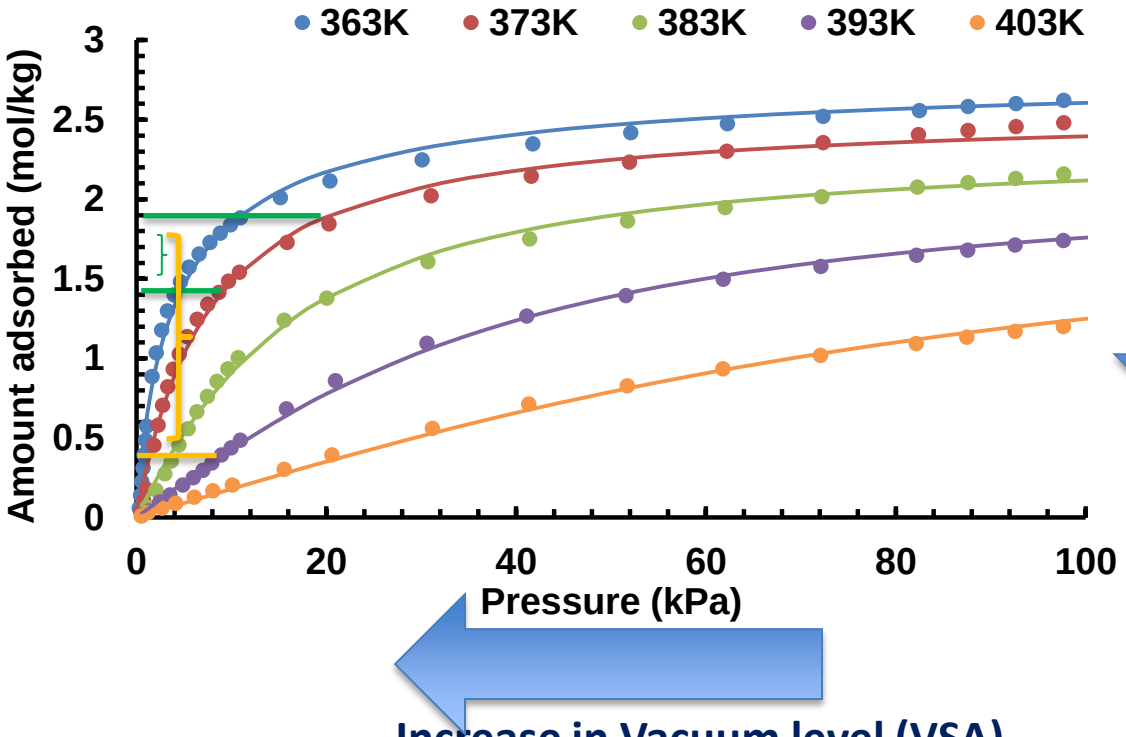
- Promising energy efficiency for capturing CO_2 in coal and cement plants using the SARC adsorption technology
- VTSA reduces the required temperature swing by 20-30 K relative to TSA for achieving a given working capacity
- Polyethyleneimine(PEI) sorbents proved to be the best suited for SARC
- Dilution of CO_2 by the desorption of water enables good desorption driving force in SARC (VTSA effect)
- A multistage bench scale reactor setup was designed and constructed for demonstration and validation of the SARC concept

Acknowledgement:

- Norwegian Research Council for funding SARC project ((grant no. 268507/E20)
- EPT management, lab manager and technicians

The Research Council of Norway

Adsorption concept- Isotherm Model



Increase in Temperature (TSA)

Working capacity- VSA

Working capacity- VTSA

Increase in Vacuum level (VSA)

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