Demonstration of Novel Swing Adsorption Reactor Cluster (SARC) for post combustion \( \text{CO}_2 \) capture

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Outline

• SARC concept
  – What?
  – How?
  – Why?
• SARC-01 (Small reactor)
  – Study 01- Comparative study
  – Study 02- Sorbent screening ‘
• SARC-02 (Bigger reactor)
  – Preliminary results
• Conclusion and questions
Swing Adsorption Reactor Cluster (SARC) for CO$_2$ capture

What?

Key features

• Low temperature adsorption based CO$_2$ capture
• Heat integration between the stages using a heat pump
• The sorbent regeneration combines vacuum and temperature swings

SARC cycle for capturing CO₂

How?

Working principle

- **Carbonation**: low temperature and atmospheric pressure required for a high degree of CO₂ capture by the sorbent
- **Evacuation**: some N₂-rich gas is evacuated to prevent it from reducing CO₂ purity in the subsequent regeneration stage
- **Regeneration**: pressure is reduced and temperature is increased to release the captured CO₂ from the sorbent
- **Cooling**: temperature and pressure are returned to the initial conditions for high CO₂ capture in the subsequent carbonation stage

SARC technology

Why?

• SARC has a very competitive energy penalty
• Easy retrofitting to existing plants (works on electricity)
• Lower SPECCA could be achieved if renewable electricity is used

Experiment demonstration approach

1. Small reactor demonstration (50-100 g)

2. Identifying suitable sorbent

3. Demonstration at bigger scale (10-12 kg)
First proof of technical feasibility

The small scale reactor (2 cm in diameter and 1 m in height) was used for:

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

Dhoke, C., et al., *The swing adsorption reactor cluster (SARC) for post combustion CO₂ capture: Experimental proof-of-principle.* Chemical Engineering Journal, 2018
Study 01- Comparative study (TSA vs. VTSA)

**Adsorption**

**Adsorbent:** EB-PEI

**Process conditions:** 333K & 100 kPa in 12.5% CO₂

**Factors**

- **TSA-regeneration**
  - TSA- 100% of CO₂

- **VTSA-regeneration**
  - VTSA- 5kPa

**Response**

\[
\text{Working capacity} = \frac{\text{moles of CO}_2 \text{ desorbed in VTSA step}}{\text{kg of adsorbent}}
\]

**EB-PEI** : 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO₂ sorbent supplied by KRICT (Korea Research Institute of Chemical Technology, Daejeon, South Korea)

Dhoke, C., et al., *The swing adsorption reactor cluster (SARC) for post combustion CO₂ capture: Experimental proof-of-principle*. Chemical Engineering Journal, 2018
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
- Improves the efficiency of the heat pump

Adsorbent: Polyethyleneimine (EB-PEI)-KRICT
- Adsorption 333K & 100 kPa in 12.5% CO₂
- Regeneration: VTSA- 5kPa
- Regeneration: TSA- 100% of CO₂

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

Dhole, C., et al., The swing adsorption reactor cluster (SARC) for post combustion CO₂ capture: Experimental proof-of-principle. Chemical Engineering Journal, 2018
Study 02 - Screening of sorbent

**Sorbents**

- EB-PEI
- PEI-MOF
- K/ZrO₂
- Na/ZrO₂

**Factors**

<table>
<thead>
<tr>
<th>Levels</th>
<th>Pressure (kPa)</th>
<th>Temperature swing (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>III</td>
<td>15</td>
<td>20 - 60</td>
</tr>
</tbody>
</table>

**Response**

Working capacity = \( \frac{\text{moles of CO}_2 \text{ desorbed in VTSA step}}{\text{kg of adsorbent}} \)

**EB-PEI**: 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO₂ sorbent supplied by KRICT

**PEI-MOF**: Polyethyleneimine and Metal organic framework supported on SiO₂ developed at RTI

**K/ZrO₂**: Potassium sorbent supported on ZrO₂ (K/ZrO₂) supplied by KRICT

**Na/ZrO₂**: Sodium sorbent supported on ZrO₂ (Na/ZrO₂) supplied by KRICT


Polyethyleneimine (PEI) sorbents proved to be the best.
Bigger reactor (SARC-02)
SARC- multistage fluidized bed

- Multistage Fluidized bed
  - Maintain high heat transfer rate for heat recovery or addition
  - Achieve more plug flow behaviour in the reactor
  - Flue gas with decreasing $P_{\text{CO}_2}$ as it rises should meet fresher sorbent

SARC multistage reactor with embedded heat transfer surfaces

- A four-stages reactor (2.5 m height)
- Integrated heat transfer surfaces for temperature swing
  - Heating oil is used as working fluid
- A vacuum pump is used for the vacuum swing
Multistage fluidized bed reactor installed at Energy and process engineering (EPT) on 30 August 2019
SARC-02 (Bigger reactor)
Preliminary result from bigger reactor (SARC-02)

1. Carbonation
2. Evacuation
3. Regeneration
4. Cooling
Preliminary result - adsorption performance

- Big reactor SARC 02
- Small reactor SARC 01
- Theoretical

- Adsorbent: Polyethyleneimine (EB-PEI)-KRICT
- Adsorption 333K & 100 kPa in 12.5% CO₂
Possible reasons for lower working capacity:
• Non uniform temperature?
• Difference in the pressure?

❖ Adsorbent: Polyethyleneimine (EB-PEI)-KRICT
❖ Adsorption 333K & 100 kPa in 12.5% CO$_2$
❖ Regeneration: VTSA- 10 kPa and 20 K
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 30-40 K relative to TSA for achieving a given working capacity.
- Polyethyleneimine (PEI) sorbents proved to be the best suited for SARC.
- A small reactor showed that theoretical predictions of SARC performance could be achieved in practice.
- Therefore, a bigger unit was constructed to further demonstrate the concept.
Acknowledgement:

• Norwegian Research Council for funding SARC project (Grant no. 268507/E20)
• EPT management, lab manager and technicians
• Back up
Adsorption concept - Isotherm Model

- Increase in Temperature (TSA)
- Increase in Vacuum level (VSA)

Working capacity - VSA
Working capacity - VTSA

Graph showing the amount adsorbed (mol/kg) versus pressure (kPa) at different temperatures (363K, 373K, 383K, 393K, 403K).
Study 03- Effect of steam

- **EB-PEI**
- **PEI-MOF**

### Factors

<table>
<thead>
<tr>
<th>Levels</th>
<th>H₂O (mole %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0 %</td>
</tr>
<tr>
<td>II</td>
<td>5 %</td>
</tr>
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VTSA-10 kPa and 20 K

### Response

\[
\text{Working capacity} = \frac{\text{moles of CO}_2 \text{ desorbed in VTSA step}}{\text{kg of adsorbent}}
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**EB-PEI**: 1,2-Epoxybutane functionalized polyethyleneimine supported on SiO₂ sorbent supplied by KRICT

**PEI-MOF**: Polyethyleneimine and Metal organic framework supported on SiO₂ developed at RTI

Submitted to Chemical Engineering Journal (CEJ-D-19-06367)
**Effect of steam on VTSA- 100 mbar & 20 C**

- Increase in the working capacity by the addition of the H₂O for both PEI sorbents
- Dilution of CO₂ by the desorption of water enables good desorption driving force

![Bar Chart](chart.png)

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

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