RETROFITTING CO$_2$ CAPTURE IN REFINERIES

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AMEC Foster Wheeler

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ReCap project

• Project Participant
  • SINTEF Energy Research – Project owner
  • IEAEPL (IEA Environmental Projects Ltd., the operating agent of IEAGHG)
  • CONCAWE

• Sub-Contractor:
  • Amec Foster Wheeler

• Main funding body:
  • GASSNOVA
Background

• Global refining sector contributes to around 4% of the total anthropogenic CO₂ emissions and CCS is considered one of the technologies that could be applied to curb these emissions.

• No new refineries are expected to be built in OECD countries – studying the feasibility of cost of retrofitting is important.

• It is essential to have a good understanding of the direct impact on the financial performance and market impact posed by retrofitting refineries with CO₂ capture technology.
Motivation

• Policy makers should fully understand the cost of CCS deployment in this sector in order to develop policies
• Current open literature does not provide data that are comparable to each other.
• Studies are usually done in a top-down approach and results cannot be taken out of context and are very site specific.
• A consistent bottom-up approach is necessary to identify precisely what the oil industry is likely to achieve in terms of CO$_2$ reduction, the related costs, their impact on global competitiveness.
Base case refineries

• 4 base case refineries defined:
  • Simple refinery with a nominal capacity of 100,000 bbl/d
  • Medium and highly complex refineries with nominal capacity of 220,000 bbl/d
  • Highly complex refinery with nominal capacity 350,000 bbl/d
CO₂ emissions from base case refineries

**Base Case 1**

**Base Case 2**
CO$_2$ emissions from base case refineries

Base Case 3

CO$_2$ emissions in wet flue gases
- Approx. 11% vol.
- Approx. 8-8.5% vol.
- Approx. 20% vol.
- Approx. 4% vol.

Base Case 4
## Base Case 4: Capture Cases

<table>
<thead>
<tr>
<th></th>
<th>CO₂ [t/h] @ operating point</th>
<th>% of total CO₂ emissions</th>
<th>CO₂ %vol</th>
<th>CO₂ %wt</th>
<th>Flue gas [t/h] @ operating point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POW</td>
<td>76.0</td>
<td>20.9%</td>
<td>4.23</td>
<td>6.6</td>
<td>1160.5</td>
</tr>
<tr>
<td></td>
<td>21.4</td>
<td></td>
<td>8.1</td>
<td>12.9</td>
<td>165.5</td>
</tr>
<tr>
<td><strong>D2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC</td>
<td>53.1</td>
<td>11.4%</td>
<td>16.6</td>
<td>24.6</td>
<td>215.9</td>
</tr>
<tr>
<td><strong>D3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDU-A/VDU-A</td>
<td>49.2</td>
<td>10.5%</td>
<td>11.3</td>
<td>17.2</td>
<td>286.5</td>
</tr>
<tr>
<td>CDU-B/VDU-B</td>
<td>49.2</td>
<td>10.5%</td>
<td>11.3</td>
<td>17.2</td>
<td>286.5</td>
</tr>
<tr>
<td><strong>D5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMR</td>
<td>19.8</td>
<td>25.1%</td>
<td>17.7</td>
<td>26.7</td>
<td>438.6</td>
</tr>
<tr>
<td></td>
<td>97.5</td>
<td></td>
<td></td>
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</tbody>
</table>

### CO₂ emissions [t/h] @ operating point
<table>
<thead>
<tr>
<th></th>
<th>CO₂ emissions [t/h] @ operating point</th>
<th>% of total CO₂ emissions</th>
<th>Avg CO₂ vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>04-01</td>
<td>D1</td>
<td>97.4</td>
<td>20.9</td>
</tr>
<tr>
<td>04-02</td>
<td>D1+D3+D4</td>
<td>195.8</td>
<td>42.0</td>
</tr>
<tr>
<td>04-03</td>
<td>D1+D2+D3+D4+D5</td>
<td>366.2</td>
<td>78.5</td>
</tr>
<tr>
<td>04-04</td>
<td>D5</td>
<td>117.3</td>
<td>25.1</td>
</tr>
<tr>
<td>04-05</td>
<td>D1+D3+D4+D5</td>
<td>313.1</td>
<td>67.1</td>
</tr>
<tr>
<td>04-06</td>
<td>D1+D2+D3+D4</td>
<td>248.9</td>
<td>53.3</td>
</tr>
</tbody>
</table>
Post-combustion CO₂ capture using MEA
Results from simulations

Reboiler steam consumption vs CO2 captured for all cases

Compressor power vs CO2 captured for all cases

Fan Power vs CO2 captured for all cases

Pump power vs CO2 captured for all cases
Methodology for techno-economic analysis

16 CO₂ capture cases

4 cases for detailed assessment
01-03, 02-02, 04-03 and 04-04

12 cases for simplified assessment

Case Characteristics

Detailed equipment list
Equipment cost
Total Direct Cost
Total Indirect Cost
Total Plant Cost
Total Capital Requirement

Number of employees & maintenance percentages
Utilities & materials consumption

Fixed OPEX
Variable OPEX

Total OPEX

KPIs of the 4 cases

Evaluation and analyses of the 16 CO₂ capture cases from the 4 refineries

Case Characteristics

Equipment cost
Total Direct Cost
Total Indirect Cost
Total Plant Cost
Total Capital Requirement

Number of employees & maintenance percentages
Utilities & materials consumption

Fixed OPEX
Variable OPEX

Total OPEX

KPIs of the 12 cases
Plot plan example
Base Case 4: Cost of retrofitting CO$_2$ capture
Important factors affecting CO₂ avoidance cost

• Utility plant
  • NG cost

• CO₂ capture plant
  • CO₂ concentration
  • Quantity of CO₂ captured
  • Flue Gas Desulphurization units

• Interconnecting sections
Summary

• ReCAP has evaluated the cost of retrofitting CO₂ capture technologies in an integrated oil refinery and understand its implication to:
  • CO₂ avoidance cost
  • Refinery fuel balance
  • Utilities requirement
  • Constructability

• Provided industry with data and tools to estimate impact of CO₂ capture in their respective refineries
## Summary

<table>
<thead>
<tr>
<th>CO₂ avoidance cost ($/t_{CO₂, avoided})</th>
<th>Characteristics</th>
<th>ReCap Cases</th>
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</thead>
<tbody>
<tr>
<td><strong>Very high</strong></td>
<td>Very low CO₂ concentration in flue gas (4-5%) coupled with a small amount of CO₂ captured (around 750 kt_{CO₂}/y)</td>
<td>04-01</td>
</tr>
<tr>
<td><strong>High range</strong></td>
<td>Low to medium CO₂ concentration in flue gas (6-9%), very low amount of CO₂ captured (300-600 kt_{CO₂}/y), significant fraction of the flue gases require FGD (50-100%) or a combination of these factors</td>
<td>02-04, 01-02, 01-01, 03-01, 01-03, 04-02</td>
</tr>
<tr>
<td><strong>Medium range</strong></td>
<td>Low to medium CO₂ concentration in flue gas (6-9%), low amount of CO₂ captured (600-750 kt_{CO₂}/y), small fraction of the flue gases require FGD (20-50%) or a combination of these factors</td>
<td>03-02, 04-06, 02-02, 02-01</td>
</tr>
<tr>
<td><strong>Low range</strong></td>
<td>Medium to high CO₂ concentration in flue gas (10-18%), large amount of CO₂ captured (2000-3000 kt_{CO₂}/y), small fraction of the flue gases require FGD (&lt;10%) or a combination of these factors</td>
<td>03-03, 02-03, 04-05, 04-04, 04-03</td>
</tr>
</tbody>
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