Integrated dynamic system study

Dynamical assessment with an integrated model of a Post Combustion Capture Plant at a Pulverized Coal Plant and CO₂ downs stream compression unit.

Robert de Kler, Adam van den Haar, Purvil Khakharia
Why an integrated dynamic simulation?

**Capture**
- Steam and flue gas
- Operational flexibility
- Emergency shutdowns
- Operational start-up and shutdowns

**Transport**
- CO₂ quality from capture plant
- Operational flexibility of capture plant and storage
- Emergency shutdowns
- Operational start-up and shutdowns

**Storage/Utilization**
- CO₂ quality from Transport
- Operational flexibility of upstream process units
- Emergency shutdowns
- Operational start-up and shutdowns

**Capture plant**
- Water management and solvent inventory
- Stripper reboiler and steam cycle dynamics
- Supervisory control optimization (minimizing energy footprint)
- CO₂ quality

**Transport**
- Accidents / maintenance
- Higher transport pressures
- Transport efficiency optimization
- Gas composition (impurities)
- Heat loss and temperature dynamics
- Formation of gas phase CO₂

**Storage/Utilization**
- Injectivity pressure and temperature
- Accidents / maintenance
- Dry-out near well zone
- Storage efficiency

Complex integrated system
Integrated dynamic simulation of the CCS chain

TNO pilot plant at EON is used and steady-state models of the demonstration post-combustion plant (250 MWe) process.

Dynamic model of an absorber/stripper is presented and the results different relevant transient operational scenarios.

Issues regarding the operability of the absorber column in case of load-varying, water management, upstream power-plants and downstream CO2 compression has been analysed and discussed.
Model development

- Modelica: object oriented, open source modeling language

- Used/adapted Modelica libraries:
  - Thermal Separation (TU Hamburg)
  - Thermopower (TU Delft and Politecnico di Milano)

- Model based on pilot plant properties/geometry

- Validation and parameter fitting with TNO pilot plant
Model development
Model validation Capture Plant

e.g.: Case A → Decrease in flue gas flow rate
Model validation Capture Plant
Model validation Capture Plant
System model Post Combustion Capture

Capture plant including CO2 Compression (Modelica)
CO$_2$ Compression generic compressor model
E.g.: Increase in flue gas flow

<table>
<thead>
<tr>
<th></th>
<th>0h</th>
<th>2h</th>
<th>2h15m</th>
<th>5h</th>
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</thead>
<tbody>
<tr>
<td><strong>Flue gas flow [kg/s]</strong></td>
<td>97.8</td>
<td>97.8</td>
<td>244.6</td>
<td>244.6</td>
</tr>
<tr>
<td><strong>CO2 in flue gas [mol/mol]</strong> (absorber inlet)</td>
<td>0.1146</td>
<td>0.1146</td>
<td>0.1434</td>
<td>0.1434</td>
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<tr>
<td><strong>Flue gas temperature [°C]</strong> (absorber inlet)</td>
<td>45.9</td>
<td>45.9</td>
<td>45.9</td>
<td>45.9</td>
</tr>
<tr>
<td><strong>Reboiler duty [MW]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control of reboiler temperature</td>
<td></td>
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## Model main parameters

<table>
<thead>
<tr>
<th></th>
<th>Dynamic model</th>
<th>Aspen model</th>
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<tbody>
<tr>
<td>Flue gas flow [kg/s]</td>
<td>244.6</td>
<td>244.6</td>
</tr>
<tr>
<td>Lean solvent flow [kg/s]</td>
<td>1079</td>
<td>980</td>
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<tr>
<td>Capture rate [%]</td>
<td>90.04</td>
<td>90.25</td>
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<tr>
<td>Reboiler duty [MW]</td>
<td>172.86</td>
<td>160.74</td>
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<tr>
<td>Specific heat duty [kJ/kgCO2]</td>
<td>3692</td>
<td>3422</td>
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<tr>
<td>MEA wt.% (lean)</td>
<td>28.2</td>
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<tr>
<td>Lean loading [mol/mol]</td>
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<td>0.273</td>
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<tr>
<td>Rich loading [mol/mol]</td>
<td>0.486</td>
<td>0.489</td>
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</table>
Increase in flue gas flow

![Graphs showing increase in flue gas flow over time](image)
Increase in flue gas flow
Final steady state value

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Base</th>
<th>Case A</th>
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<tr>
<td>Capture Rate</td>
<td>%</td>
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<tr>
<td>Reboiler duty</td>
<td>MW</td>
<td>172.9</td>
<td>172.8</td>
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<tr>
<td>L/G</td>
<td>kg/kg</td>
<td>4.41</td>
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<tr>
<td>V_liq total</td>
<td>m³</td>
<td>1995.7</td>
<td>1994.0</td>
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<tr>
<td>Rich loading</td>
<td>mol/mol</td>
<td>0.486</td>
<td>0.485</td>
</tr>
<tr>
<td>Lean loading</td>
<td>mol/mol</td>
<td>0.273</td>
<td>0.269</td>
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<tr>
<td>Specific heat duty CO₂</td>
<td>kJ/kg</td>
<td>3692</td>
<td>3691</td>
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</tbody>
</table>
Summary

Simulation model provides technical insight in dynamic transients and can be used as an engineering design tool to:
- evaluate control strategies
- review equipment sizing
- address interface issues
- evaluate operational optimisation
- identify risk wide range of operational conditions

Integration with transport and storage infrastructure a must!
Acknowledgements

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  (http://www.co2-cato.org)
THANK YOU!

Questions?