Modelling of post combustion capture plant flexibility

Workshop on operating flexibility of power plants with CCS
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Outline

- Background and motivation
- Dynamic modelling
- Verification/validation
- Preliminary results
- Further work
Background and motivation
Dynamic modelling and simulation of CO₂ absorption activities in SINTEF and NTNU

- BIGCO2 – a project started in 2005 as a continuation of a Strategic Institute Project (CO2-SIP) from 2001
  - Dynamic modelling and simulation of CO₂ capture processes from 2001
    - Fuel cell and membrane-reactor
  - Dynamic modelling and simulation of absorption systems for post-combustion (2005) – co-operation with University of Austin, Texas, group of Gary Rochelle
  - 1 ½ year – to end 2006
    - Dynamic model of an absorber column in gPROMS
    - Some initial analyses of start-up and changing load in power-plant
    - One paper describing temperature profiles in the column and one paper describing the model and the results of the start-up and changing load simulations

- From January 2009
  - Revitalise the work from 2005/2006
  - Includes some master-students
    - Summer-jobs
    - Project and master-thesis work
  - Extra funding (BIGCCS) to include PhD
  - SINTEF work appr. 1 man-year
Main challenges - steady state

- Heat requirement in reboiler
- Investment cost
- Electricity demand
- Solvent degradation
- Solvent volatility and environmental effects
- Water-balance
- Foaming
Motivation for dynamic modelling and simulations of post-combustion absorption systems (1)

Absorption systems are regarded as most flexible of all proposed capture processes with respect to operation, but

- The upstream power plant might operate with a varying load.
  - The power plant responds very quickly to changes in operating conditions
  - What about the response in the downstream capture plant?
    - Will non-standard conditions (such as flooding and a higher pressure drop than can be treated by the blower) occur during transient conditions? If so, how should the plant be operated in an optimal manner?
    - How will the transient operation affect the water-balance of the system?
Motivation for dynamic modelling and simulations of post-combustion absorption systems (2)

Absorption systems are regarded as most flexible of all proposed capture processes with respect to operation, but

- There are no experience with large scale integration with power-plants.
- The capture plant may reduce the flexibility of the power plant.
  - Dynamic simulation to identify any operational bottlenecks at transient conditions in the planned integrated plant
- The absorber/stripper process is complex, optimal design and operation interfere with each other
- Improvements of the absorption process (e.g. inter-cooling, lean vapour recompression, multi-stage stripping) add complexity
  - May imply more complex operations
- In case of bio-fuels and coal-based power plants, the condition of the fuel might vary during operation implying varying flue gas composition
Motivation for dynamic modelling and simulations of post-combustion absorption systems in SINTEF and NTNU

- Main focus development of improved and/or new solvent system and improved processes
- The new solvent systems and processes must perform adequate at transient conditions as well as steady state
  - Simulations (both solvent systems and processes)
  - Test in new pilot plant (is flexible, but not all process configurations can be tested)
Modelling
BIGCO2: Task B: Post Combustion CO$_2$ Capture
Plans for activity: Process model development and analysis

- **Objective (2009-2011):**
  - To develop a simplified dynamic model capable of evaluate generic absorption based CO$_2$ capture processes under transient conditions. Furthermore, it shall be used to develop and assess improved absorption process configuration and it might as well be used to develop a proper control philosophy and system

- **Overall plan for 2009**
  - The initial work in 2009 will focus on setting up specifications for the model and deciding on the platform. Work will begin on development and implementation of models for different units
    - Started with existing gPROMS model
    - Implementing in Matlab
      - Same framework as in-house steady state tool CO2SIM
      - gPROMS expensive for SINTEF (not NTNU)
Modelling approaches

Source: A. Lawal et al., Fuel, in press
Model assumptions – existing model

- Plug flow regime;
- One-dimensional time-dependent differential mass and energy balances for both gas and liquid phases;
- Linear pressure drop (fixed outlet pressure);
- Ideal gas phase (due to low pressure);
- MEA used as the solvent, meaning that all required thermodynamics are implemented for this specific solvent;
- Rate-based model
- Mass and heat transfer are described by the two-film theory;
- No accumulation in gas and liquid films;
- Liquid film reactions are accounted for as an enhancement factor in the overall mass transfer coefficient;
- Fluxes of CO\(_2\), H\(_2\)O and MEA between the two phases are allowed for in both directions;
- Thermal equilibrium is assumed between the liquid and solid phases;
- Water vapor condenses at the wall and at the gas-liquid interface; and
- The packing material specific area is used as the effective contact area between the gas and liquid phases.
Model validation
Steady state

- gPROMS model compared to pilot data at UT
- gPROMS model compared to Aspen Plus, Ratesep model
Steady state – planned model validation

- Matlab model compared to in-house tool CO2SIM
- Matlab model compared to newly updated MEA campaign in lab pilot plant at NTNU-SINTEF as well as new pilot plant in Trondheim
Dynamic model validation - planned

- Possible Cesar Esbjerg plant MEA campaign
- New pilot planned MEA campaign in March/April 2010
Preliminary results
gPROMS model results


  - Dynamic simulation
    - ✓ Start-up
    - ✓ Load-reduction
Start-up simulation: Assumptions

- The column at the start of the simulation was filled with air at ambient temperature (293 K);
- The start-up pressure was at atmospheric pressure;
- Heat loss was not accounted for before the liquid was fed into the column;
- In the beginning (before gas was fed to the column) the liquid was fed from a storage tank containing the same amount of CO₂ as under normal operation (same and constant lean loading);
- The liquid feed rate was ramped with an increase of approximately 3.5 moles per second;
- No flue gas was fed to the column before the desired liquid feed rate was approached;
- The flue gas feed rate was ramped with an increase of 0.5 moles per second.
Liquid flow rate and flue gas flow rate during start-up.
Liquid temperature profiles during start-up
Load-changing simulations - assumptions

- Coal power plant
- Change in load from 100 – 50%
  - Reduce in flue gas flow rate
  - Will affect temperature – but not saturation temperature (constant flue gas composition)
- Included pre-cooler and time delay upstream absorber
- Simulation strategy:
  - 5 minutes at base load conditions
  - Flue gas flow rate to the cooling tower reduced linearly from 300 mol/s to 150 mol/s in 8 minutes
  - 9 minutes simulated to allow the system to stabilize at the new steady-state values
- Two control cases
  1. No reduction in liquid flow
  2. Reduction so that final removal rate same as at 100% load
Change in L/G and capture rate

L/G

Removal rate
Conclusions and further work
Conclusion

- In order to study the effect of transient conditions, the whole capture plant must be modelled.
- For integrated processes, other parts should be modelled in the same tool (i.e. the power plant and CO₂ compression), but might require a much simple absorber model.
- For plant control and optimisation a much simpler absorber model might be developed.
Further work

- Transient validation of absorber model
- Sensitivity analysis of absorber model complexity
- Model development and implementation of other process units in the capture plant
- Validation of capture plant model
- Include other solvent systems in the model
- Connect to CO2SIM (same GUI, but different mode of operation)
- Performance studies as part of development work
Thank you for your attention!