



Business from technology

Dynamic Simulation and Simulation Tools Development of Oxyfuel-CFB Power Plant

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Content

- Background
- Objective
- Development of dynamic simulator for oxyfuel CFB power plant
- Application of the simulator – case examples
- Conclusions

Background

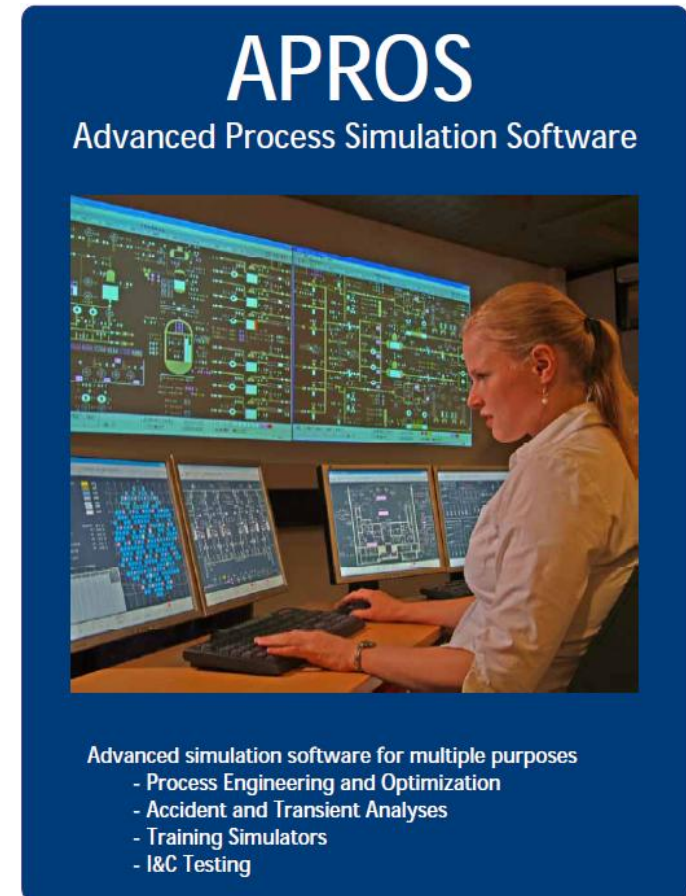
- Typically the development of new concept such as oxyfuel CFB begins with steady state modelling including mass and energy balances etc.
- **Next logical step is a analysis of process dynamics for the developed concepts**
- Currently only few comprehensive dynamic process models for the integrated oxyfuel CCS have been published → dynamic models for separate sub-processes such as ASU and boiler have been presented widely
- Compared to steady state process models a lot of detailed information is needed to build up (accurate) dynamic process model
- **Iteration between steady state and dynamic modelling is needed to develop fluent concept before the large scale demonstration**

Objectives for the development of the dynamic simulator

- The primary target is to provide information on dynamic behaviour of the **integrated** system
 - This information is essential for verifying the feasibility of the process concept and its control strategies from low level to upper level controllers
- Operability of the novel concept must be studied and guaranteed before large investment in demonstration unit
- Solid understanding of the plant dynamics is needed to develop advanced high level controls
 - Dynamic simulation supports this task by providing dynamic response data for required variables

Selection of software (1/2)

- In general, adequate simulation tool is not always available
 - Tools need to be integrated
- The APROS simulation tool provides easy on-line access for configuring and running the simulation models, solution algorithms and model libraries for full-scale modelling and dynamic simulation of processes, such as combustion power plants and nuclear power plants
- The model libraries have been comprehensively validated against data from physical process experiments
- www.apros.fi



APROS
Advanced Process Simulation Software

Advanced simulation software for multiple purposes

- Process Engineering and Optimization
- Accident and Transient Analyses
- Training Simulators
- I&C Testing

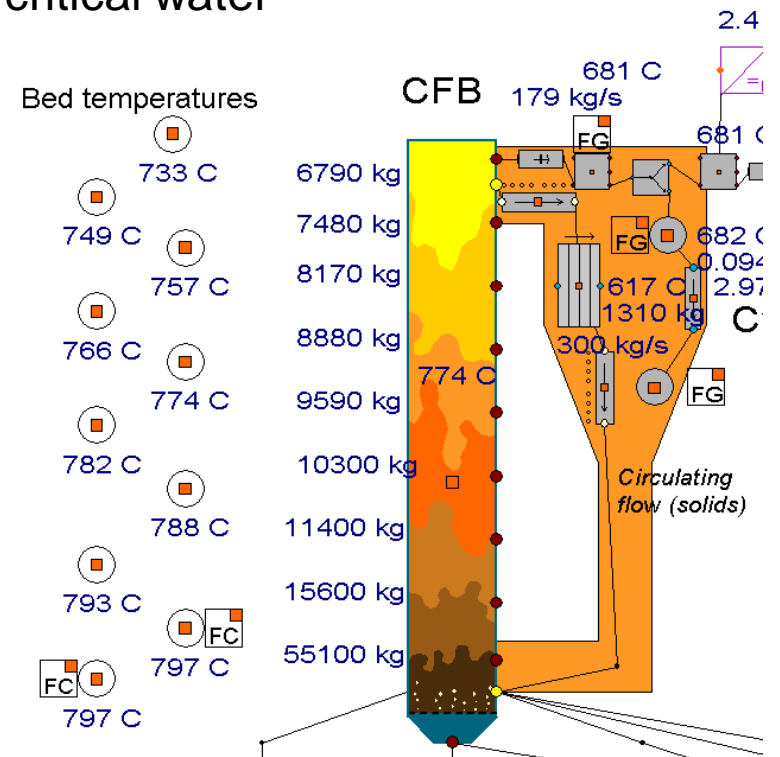
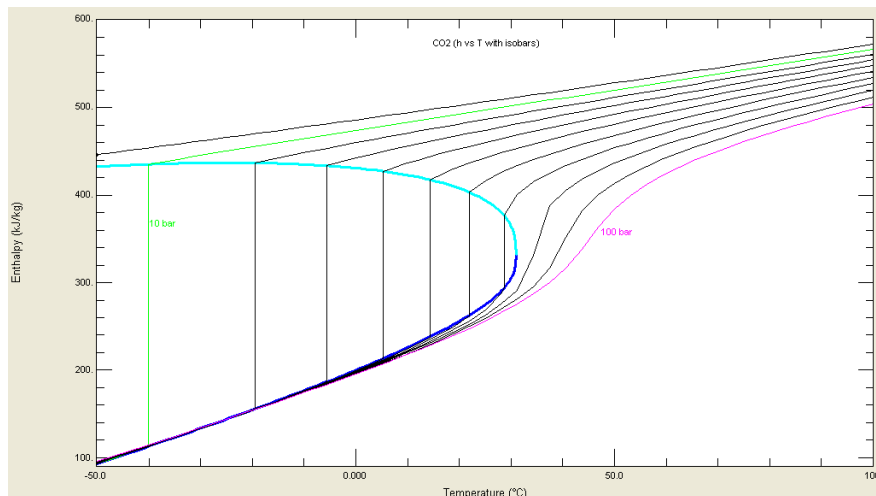
The advertisement features a woman in a white lab coat sitting at a desk with multiple computer monitors displaying complex process flow diagrams and data. The background is a dark blue gradient.

Selection of software (2/2)

- **Aspen Plus® Dynamics** is a very powerful tool to model chemical processes such as distillation processes needed for oxyfuel CCS plant
- Objective was to combine the best part of the softwares (Apros and Aspen Plus Dynamics) in order to simulate the modern process concepts with the best possible tools
 - Power plants with APROS
 - Chemical plants with Aspen

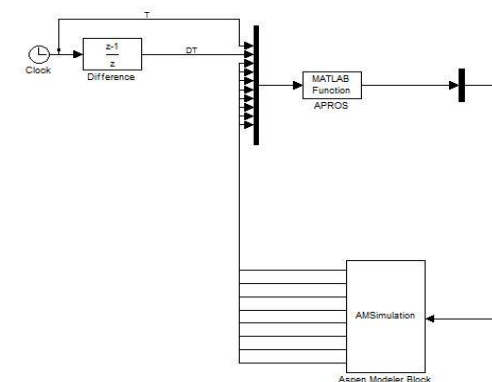
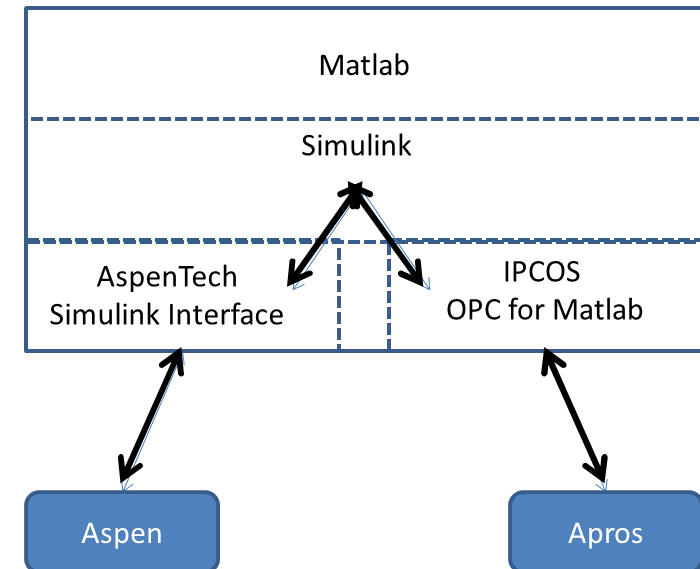
Simulation platform developments in APROS

- FLEXI BURN CFB project utilizes several recent developments
- Thermal hydraulics
 - New fluids for homogeneous model pressure-flow solver: CO₂, N₂, O₂, air
 - Improvements to 6-equation model and supercritical water
- New unit operation models
 - Circulating Fluidized Bed
 - Particle transmitter (solid material recycling)



Integration of softwares

- Several connection methods evaluated
 - Direct OPC, Excel, Matlab
 - Evaluation based on
 - Synchronization possibilities of simulator
 - Ease of configuration
- Chosen method
 - Combination of OPC and Matlab



Development of dynamic simulator

- A dynamic tool combining Apros and Aspen Dynamics simulators of the process integrate that covers ASU (Air separation unit), CFB (circulating fluidized bed boiler) with turbine Island, and CPU (CO₂ compression and purification unit) was developed
- The model includes the main process units and streams of the process to provide the characteristic dynamic features of the system
- The **control loops** and supporting calculations that were essentially required to operate the system are included

A dynamic tool combining Apros and Aspen Dynamics simulators

- Neither tool alone was able to simulate the entire ASU + CFB + CPU process **in detail** → combine the two

APROS

The APROS simulation consists of three main parts:

- ASU - BOILER Interface:** A schematic showing the connection between the Air Separation Unit (ASU) and the CFB boiler. It includes components like LOX Buffer Tank, GOX Finheaters, and GOX Headers.
- CFB boiler unit:** Divided into two sub-diagrams:
 - BOILER ISLAND - THE WATER-STEAM SIDE:** Shows the steam cycle with various pumps, valves, and heat exchangers.
 - BOILER ISLAND - THE GAS SIDE:** Shows the gas flow from the CFB reactor through various heat exchangers and turbines.
- Turbine and water cycle:** A detailed schematic of the power cycle, featuring High Pressure (HP), Intermediate Pressure (IP), and Low Pressure (LP) turbines, along with a feedwater tank, condensers, and pumps.

ASPEN PLUS DYNAMICS

The Aspen Plus Dynamics simulation covers two main units:

- Air Separation Unit:** A process flow diagram showing air entering from the left, passing through an Air Compressor (AirComp), then through a series of heat exchangers (AirExch, SubCool, LRC) and a distillation column (ExpTur) to produce LOX and GOX.
- Carbon compression and Purification Unit:** A process flow diagram showing flue gas entering from the left, passing through a Flue Gas Condensing and Heat Recovery unit, then through Feed Compression, Cleaning and Drying, and a Cryogenic CO2 separation unit. The final product is Compressed CO2 for sequestration.

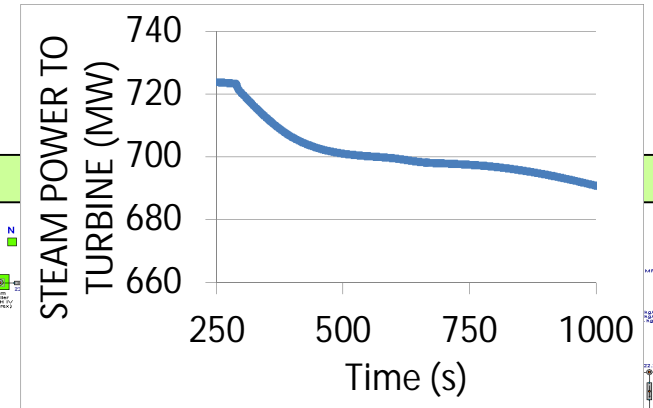
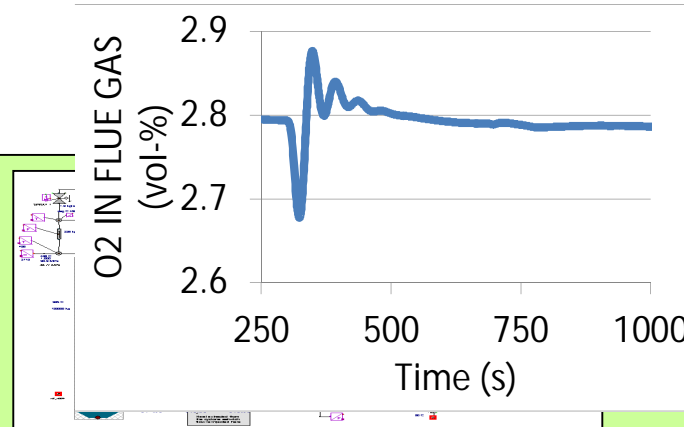
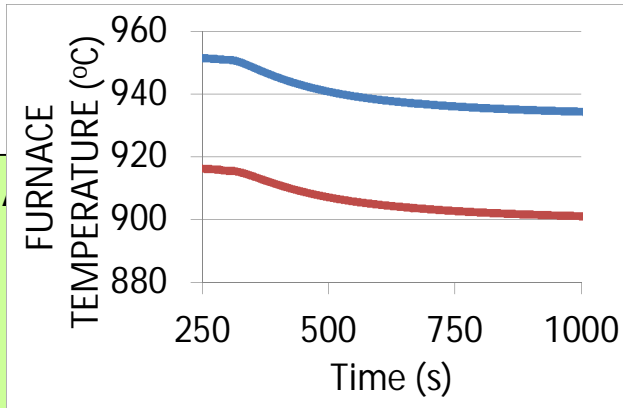
Dynamic simulation of oxyfuel CFB power plant

- Typically simulation studies include operation transients, such as
 - start-up and shut-down,
 - load changes,
 - various disturbance situations,
 - changes between air- and oxygen-firing
- Comparison and analysis of air- and oxygen-firing in above mentioned situations
 - special features of oxygen-firing e.g. effect of high flue gas recirculation on boiler behaviour and control system
 - coordination and upper level controls for the integrated power plant including ASU, boiler and CPU

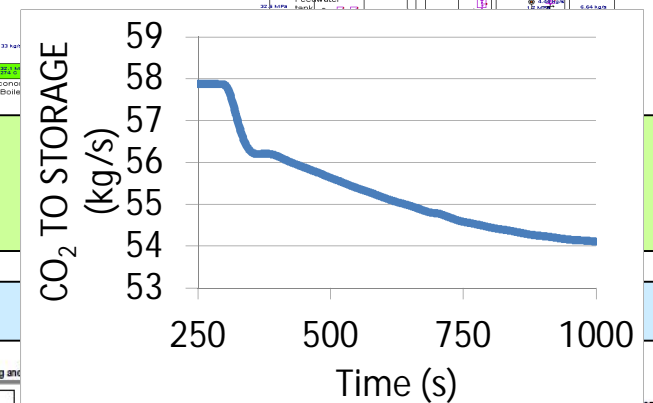
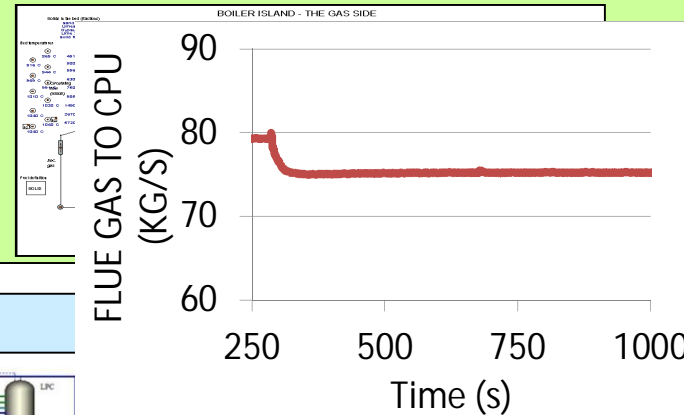
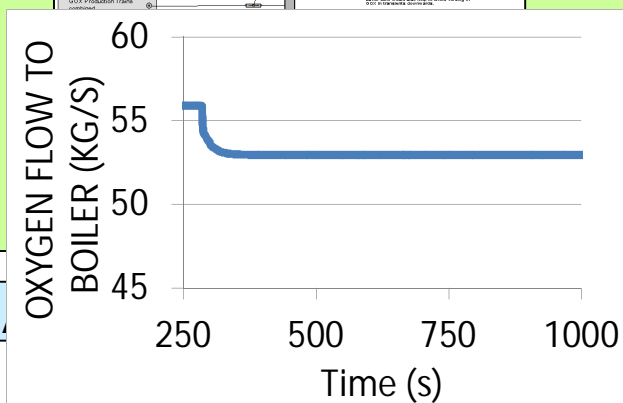
SIMULATION EXAMPLE 1:

LOAD CHANGE -5%

Simulation example – load change -5%

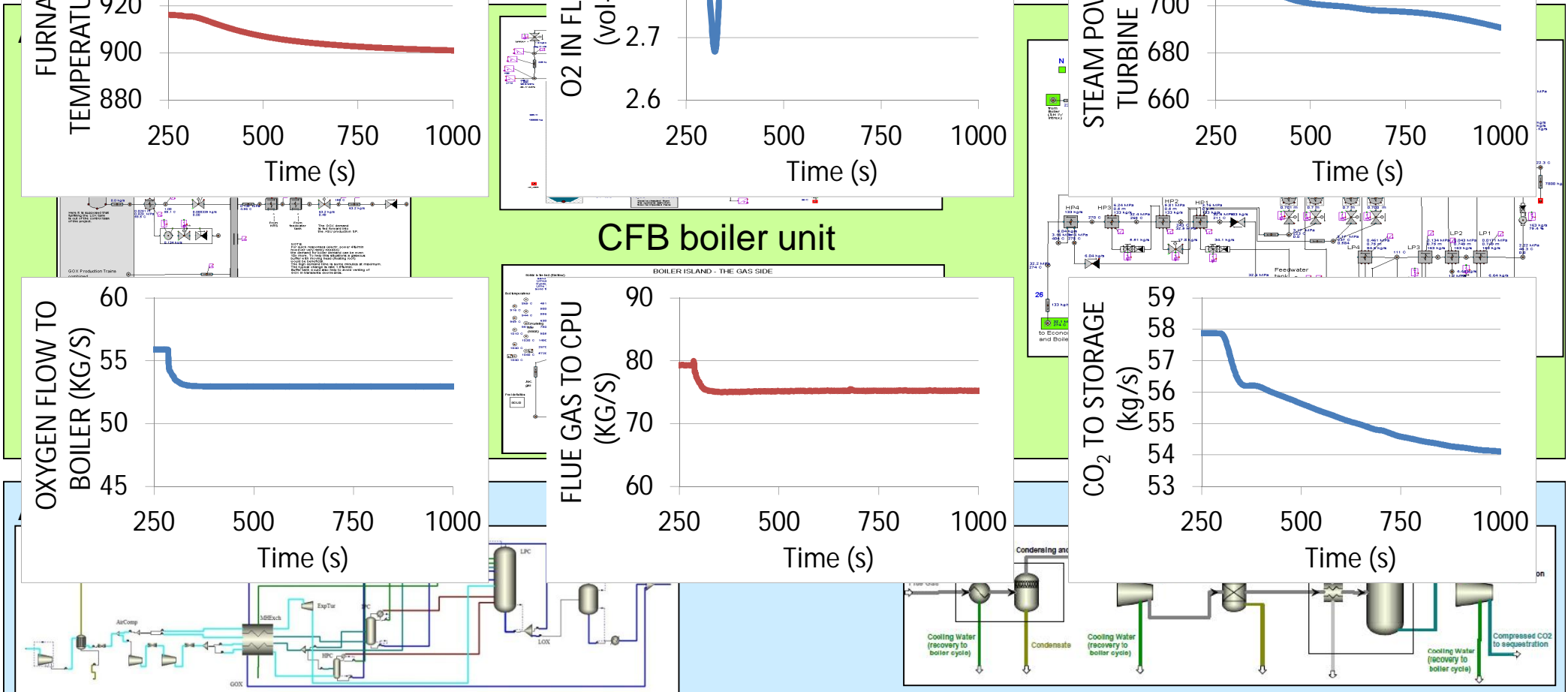


CFB boiler unit



Air Separation Unit

Carbon compression and Purification Unit



SIMULATION EXAMPLE 2:

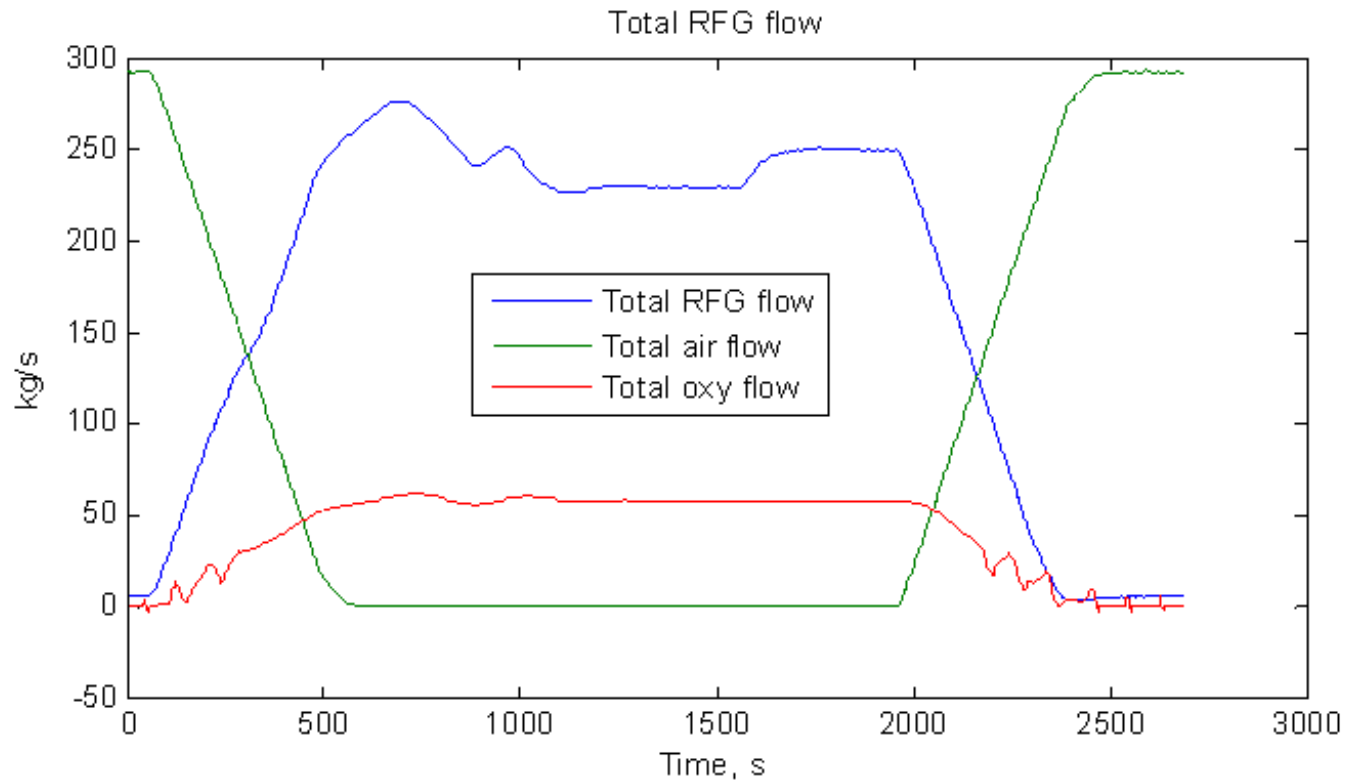
**MODE CHANGE FROM AIR TO OXY AND
BACK**

Simulation example: Mode change from air to oxy and back

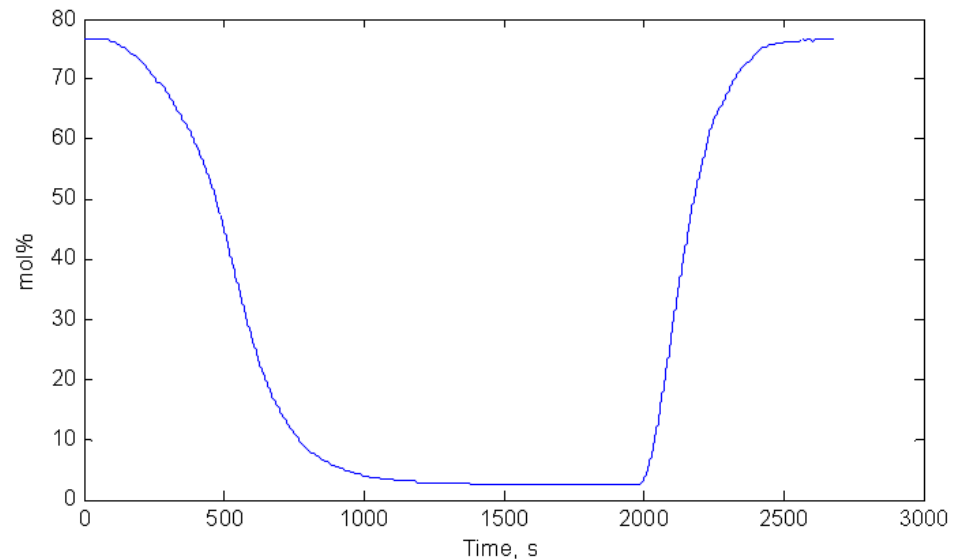
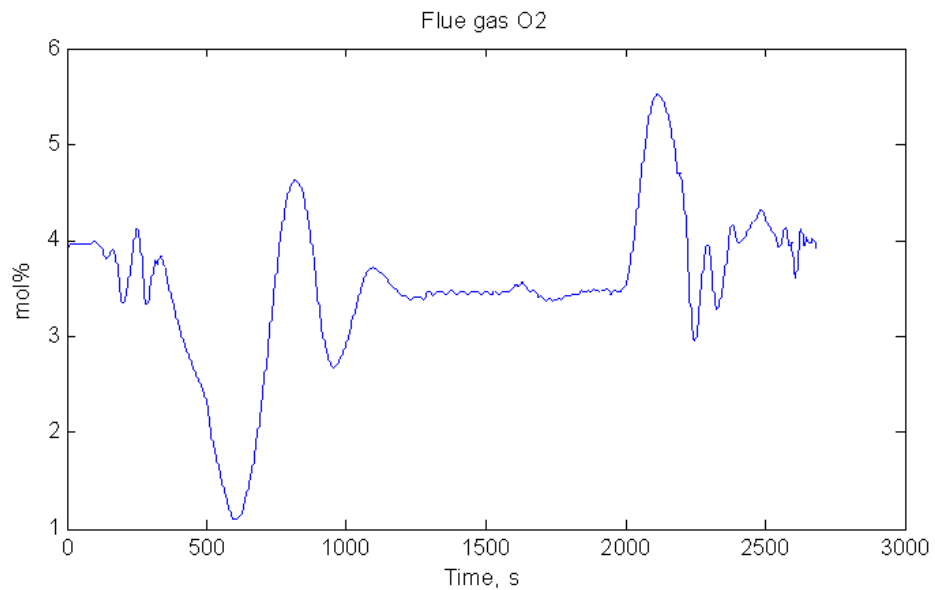
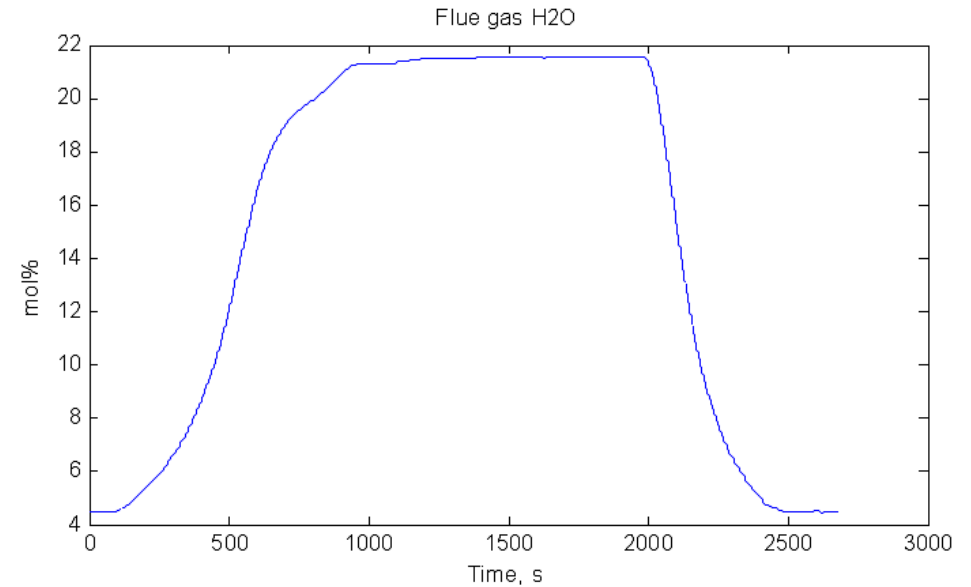
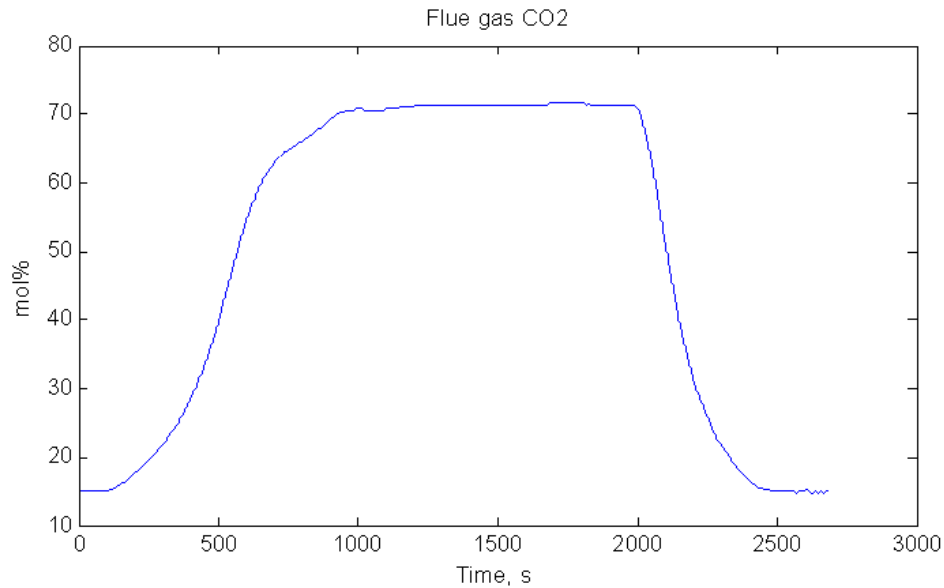
- Mode change from air mode to oxy mode and back again
- The manipulated variables:
 - Air flows
 - Oxygen flows
 - RFG flows
 - (Fuel feed is constant)
- During the changes all the set points for primary air, secondary air, primary RFG-gas secondary RFG-gas, primary oxygen and secondary oxygen flows are ramped up/down with same ramping rate
- Duration of transitions about 9 min

Simulation example: Mode change from air to oxy and back

Simulated gas flows during combustion mode change



Simulation example: Mode change from air to oxy and back: emission responses



Conclusions (1/2)

- Time dependent process model was developed for Oxyfuel CFB power plant including ASU, boiler island and CPU
- Simulation of the concept with best possible tools
 - Power plants with APROS
 - Chemical plants with Aspen
- The model performance was tested by simulating load changes and transitions between air and oxy modes
- The model provides excellent base to study dynamical behaviour of the oxyfuel CFB power plant with CCS and **to develop and optimize control strategies, upper level controls, and operational practises**

Conclusions (2/2)

- Dynamic simulation of the **integrated** oxyfuel CFB power plant with CCS is very important in order to guarantee high availability combined with high efficiency and safety operation
 - e.g. the interface between ASU and the boiler island proved to be very important part of the system from control and operation point of view
- Further development of oxyfuel CCS concepts call for dynamic simulators
 - e.g. development of **the second generation of oxyfuel CFB power plant concept** with significantly higher efficiency

Future developments in simulation tools

- Need to improve integration of different simulation tools e.g. ASPEN and APROS without matlab link
- Further development of submodels for ASU, boiler and CPU

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