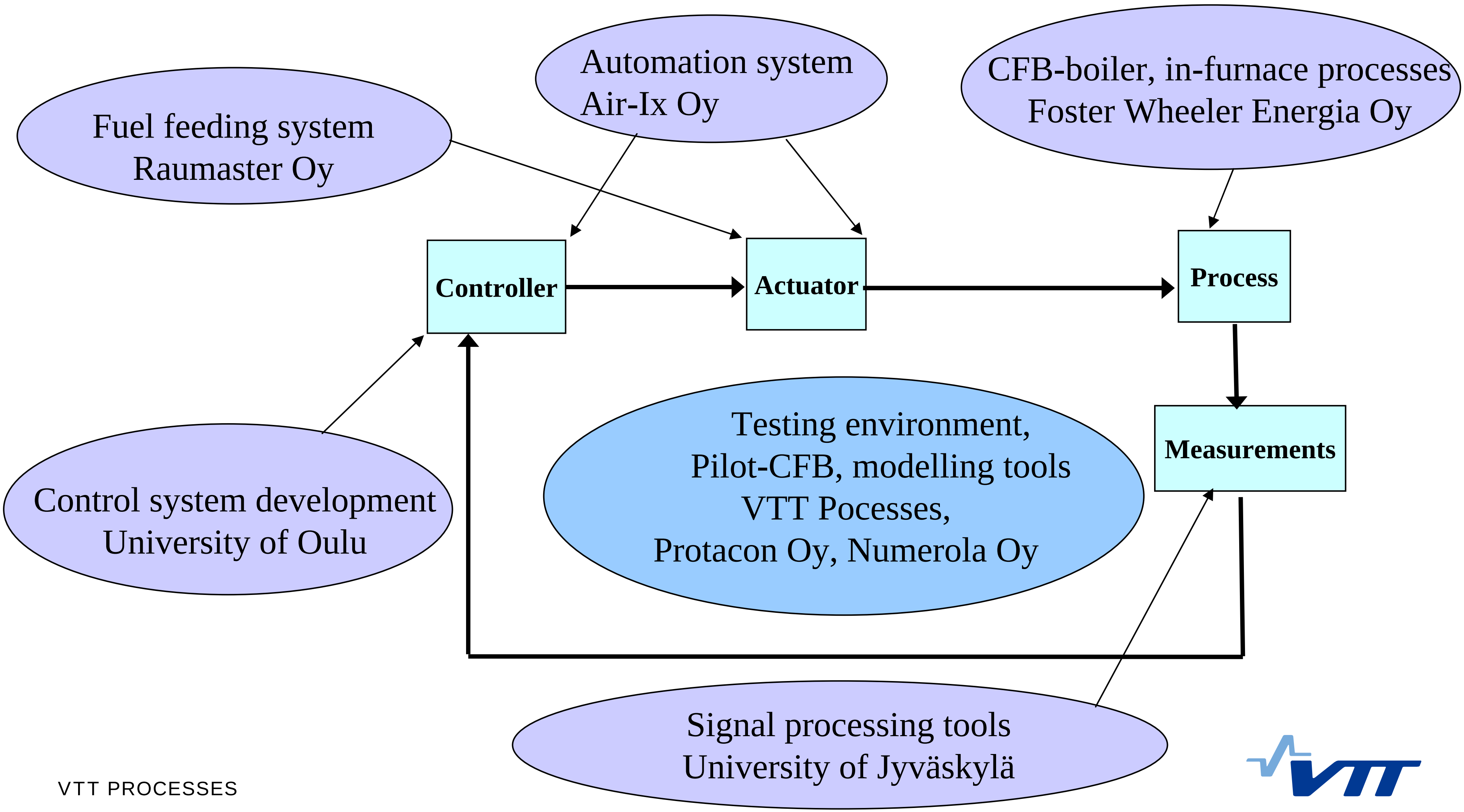
Advanced Processes Analysis and Control Methods for CFB Power Plants – Project Overview

47th International Energy Agency – Fluidized bed conversion (IEA-FBC) meeting, on October 13-14th, 2003 in Zlotniki, Poland

Advanced Processes Analysis and Control Methods for CFB Power Plants – Project Overview

- National project, which was started on March 2003
- Project is financed by
  - National Technology Agency (TEKES) + Jyväskylä Science Park
  - VTT Processes
  - Industrial partners
- Research organizations:
  - VTT Processes, University of Jyväskylä and University of Oulu

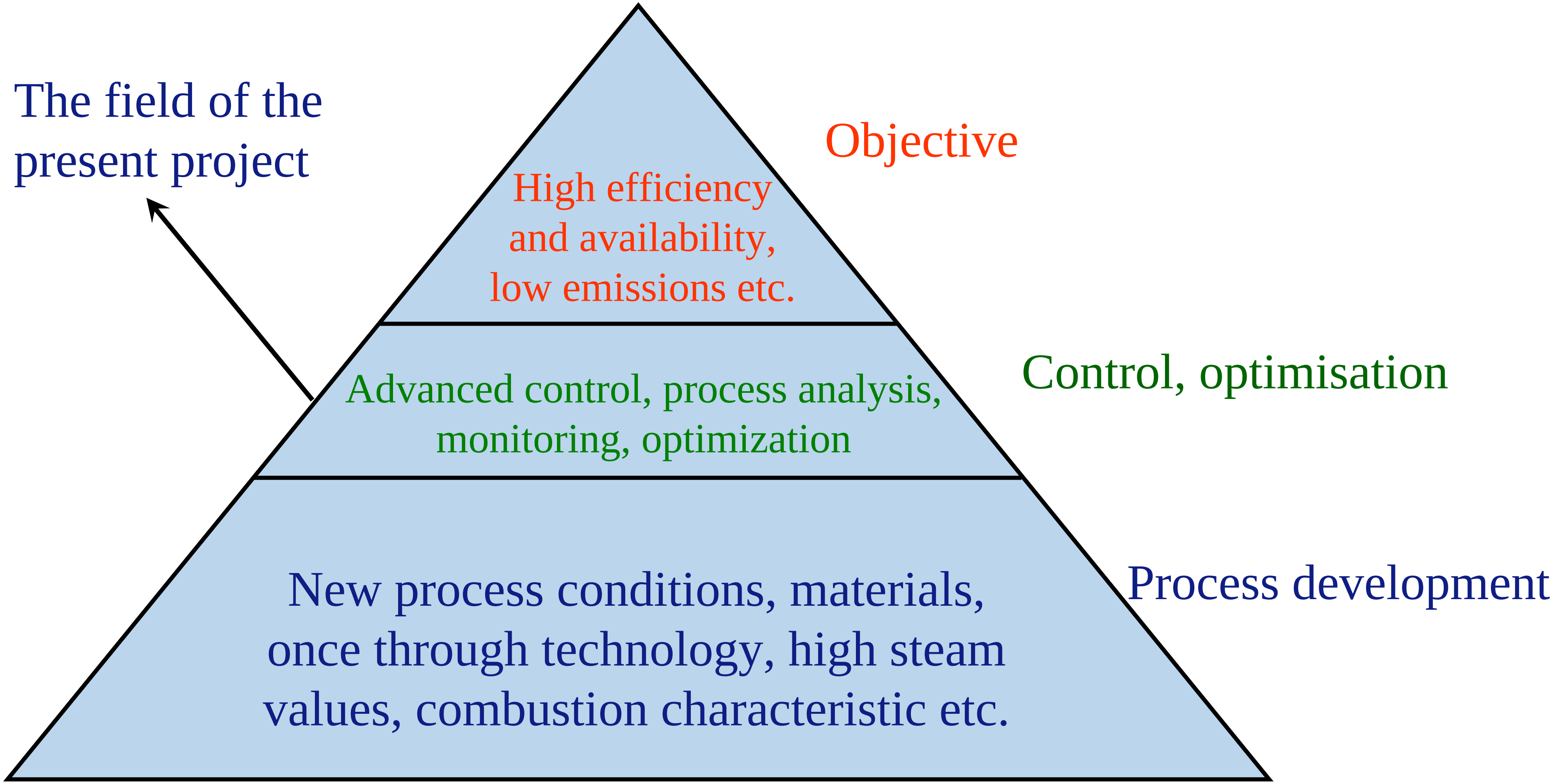
Partners and their main field in the project



Background

- Deregulation of energy markets call for high productivity and low costs
- Fuel selection will expand in the future
- Emission limits will tighten up all the time
- Large utility scale CFB boilers will be based on once thorough technology with super critical stem values
- Optimisation, availability, high efficiency, low emissions are highlighted in the future

All these above-mentioned issues set high demands for boiler automation and control systems. Also in the future, information from process measurements must be utilized more effective in optimisation and monitoring of the process.


The field of the present project
Objective
High efficiency and availability, low emissions etc.
Control, optimisation
Advanced control, process analysis, monitoring, optimization
Process development
New process conditions, materials, once through technology, high steam values, combustion characteristic etc.

Objective

The main aim of the project is:

To develop methods and tools to stabilize and optimise combustion process by utilizing advanced signal processing and control methods as well modelling tools gained with experimental data.

The work of the project can be divided into three different tasks:

Task 1: Create testing environment (based on existing CFB-pilot plant)

- utilization of the method to characterize fuel combustion behaviour (experimental procedure + modelling tool)

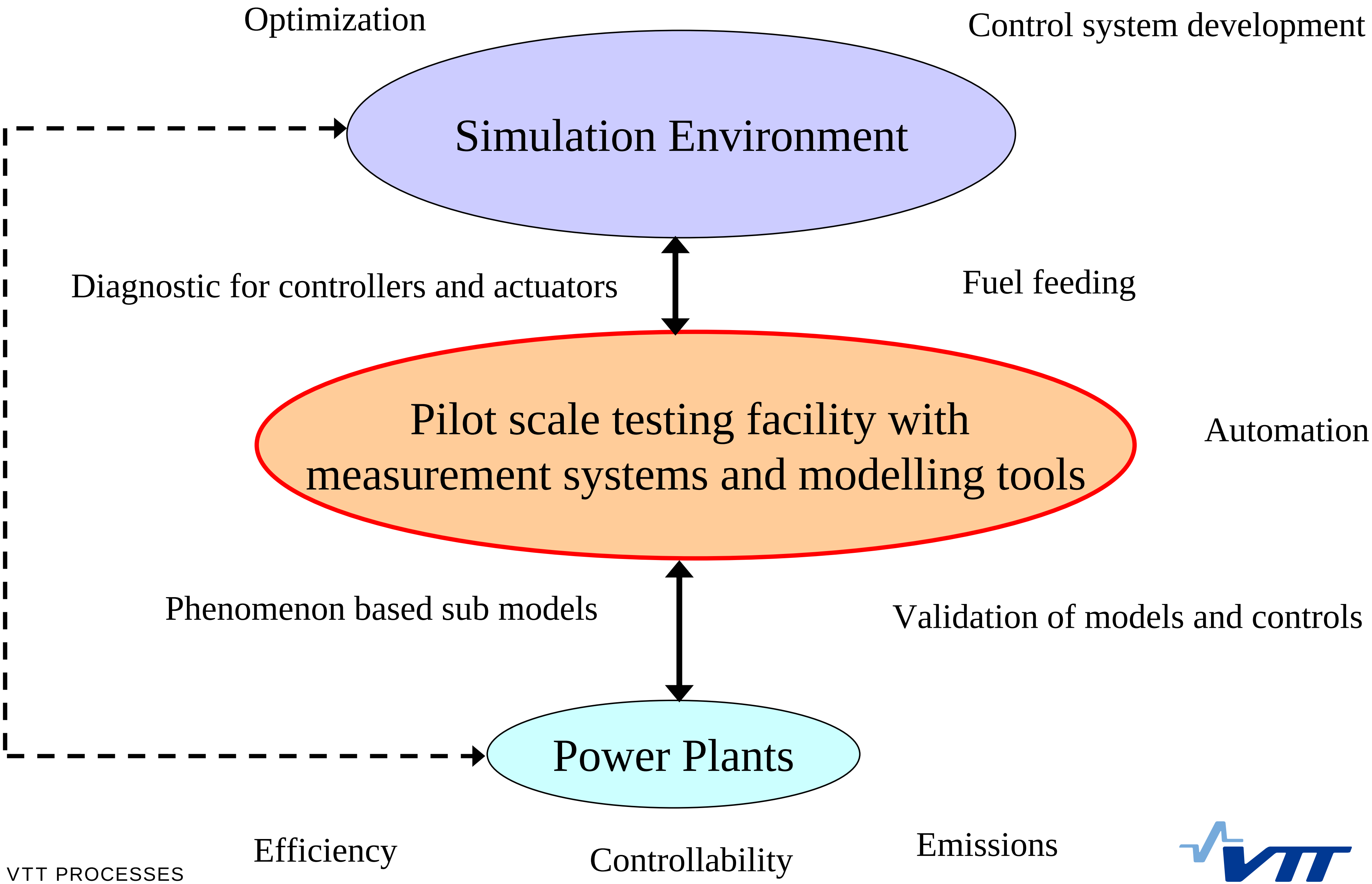
Task 2: Develop new control methods for CFB-boiler

Task 3: Create new signal processing tool for analysis of process measurements

Testing environment

Why testing environment is needed?

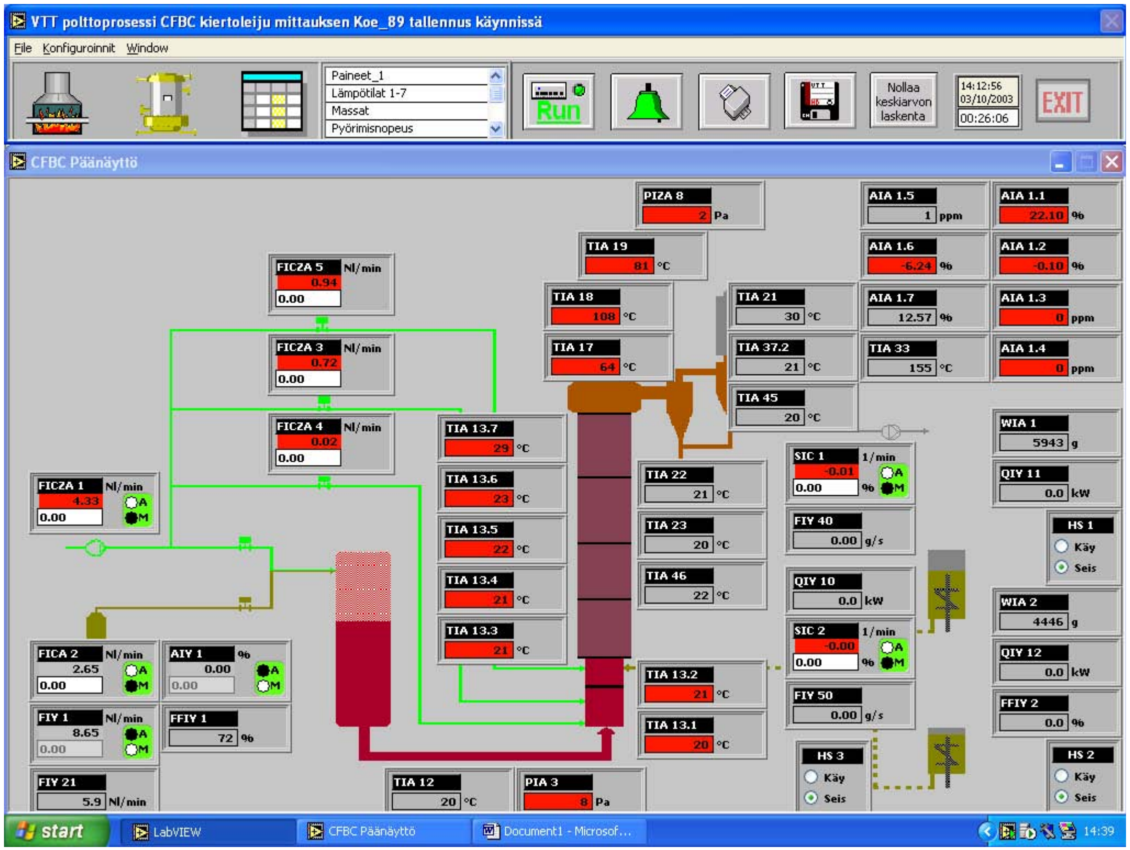
- There is need to combine control system development, carried out in simulation environments, with pilot scale experiments gained with model based tools before testing at full scale plants.
- Possibility to test and develop new control methods and measurements without restriction of full scale
- Well-controlled process conditions
- Screen out the best ideas in order to test and verify at full scale units
- Enhance process development and commissioning of new methods and tools to industrial use


Optimization
Control system development
Simulation Environment
Diagnostic for controllers and actuators
Fuel feeding
Pilot scale testing facility with measurement systems and modelling tools
Automation
Phenomenon based sub models
Validation of models and controls
Power Plants
Efficiency
Controllability
Emissions

CFBC Testing environment

CFB-pilot reactor has been equipped with commercial control software

- fast data logging (in normal use 1 second is enough → sensor time constants)
- easy to implement new calculations, control systems, model based state monitoring etc.



The method to characterize fuel combustion behaviour

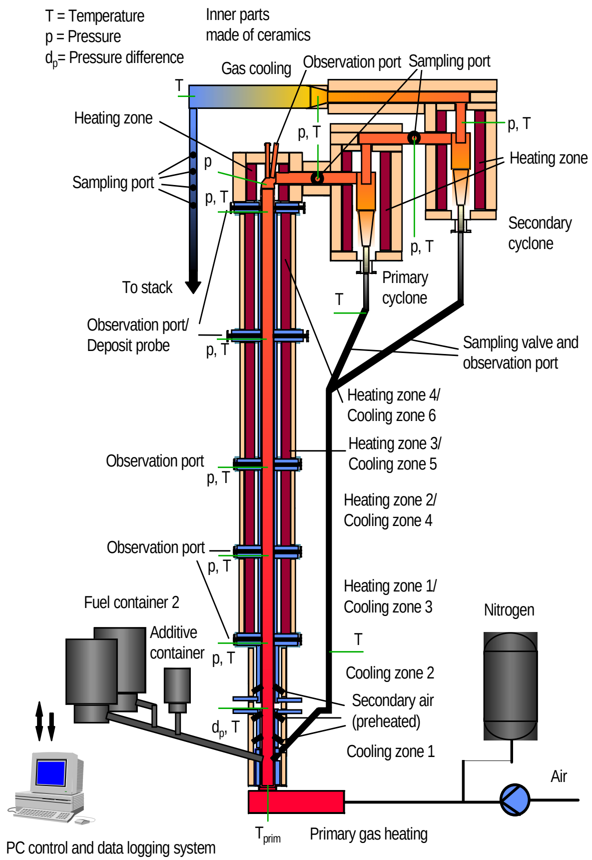
- A simplified one-dimensional time-dependent numerical model for the transient behaviour of the CFB combustor was developed for the interpretation of the transient data. In the model the delays of sample lines and the dynamics of analysers were taken into account by using transfer functions etc. Combustion process can be simulated during steady state and dynamic operation.

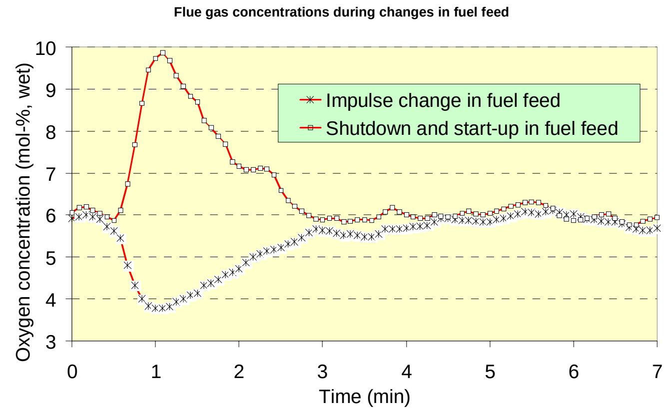
- The modelling tool for the CFB reactor consist of :

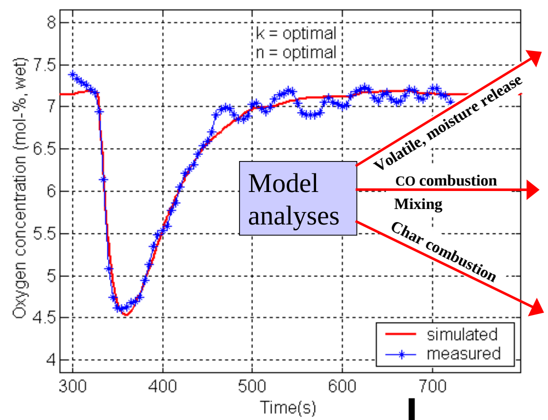
→ fuel reactivity parameters, mass balances for char fractions and main gas compounds, dynamics for analysers, sample lines, sub models for air and fuel feeds etc.

→ Dynamic 1D-model can be applied for control system development

CIRCULATING FLUIDIZED BED REACTOR





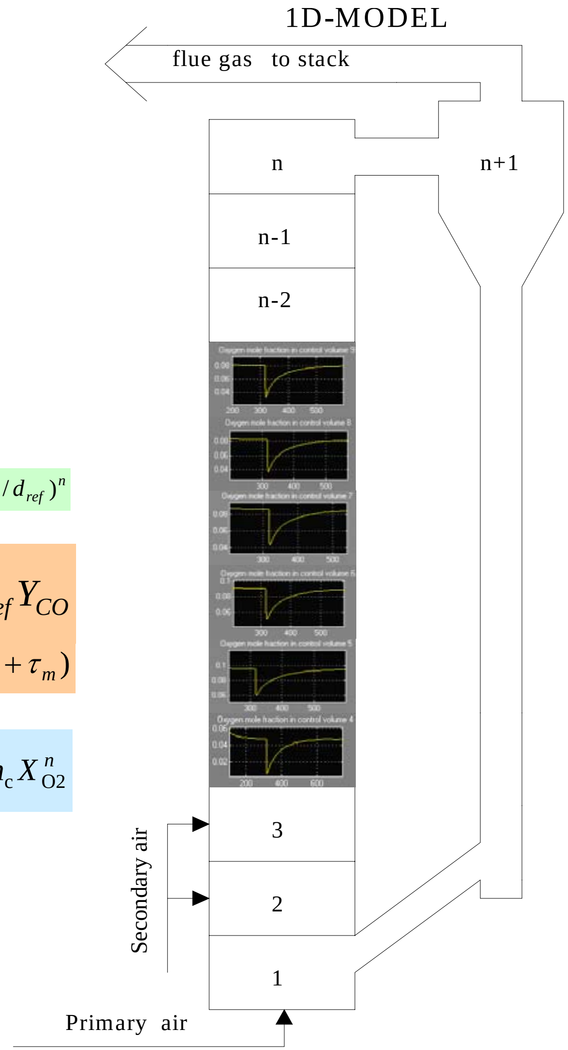


$$\tau_v = b\exp(A/T)(d/d_{ref})^n$$

$$-\frac{dY_{CO}}{dt} = k_{ef} Y_{CO}$$

$$k_{ef} = 1/(1/k_{CO} + \tau_m)$$

$$r_c = \frac{dm_c}{dt} = km_c X_{O2}^{\,n}$$



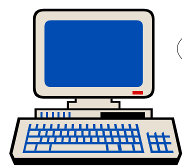
Parameters and submodels for the OTSC CFB design models and control systems

Reactivity of char

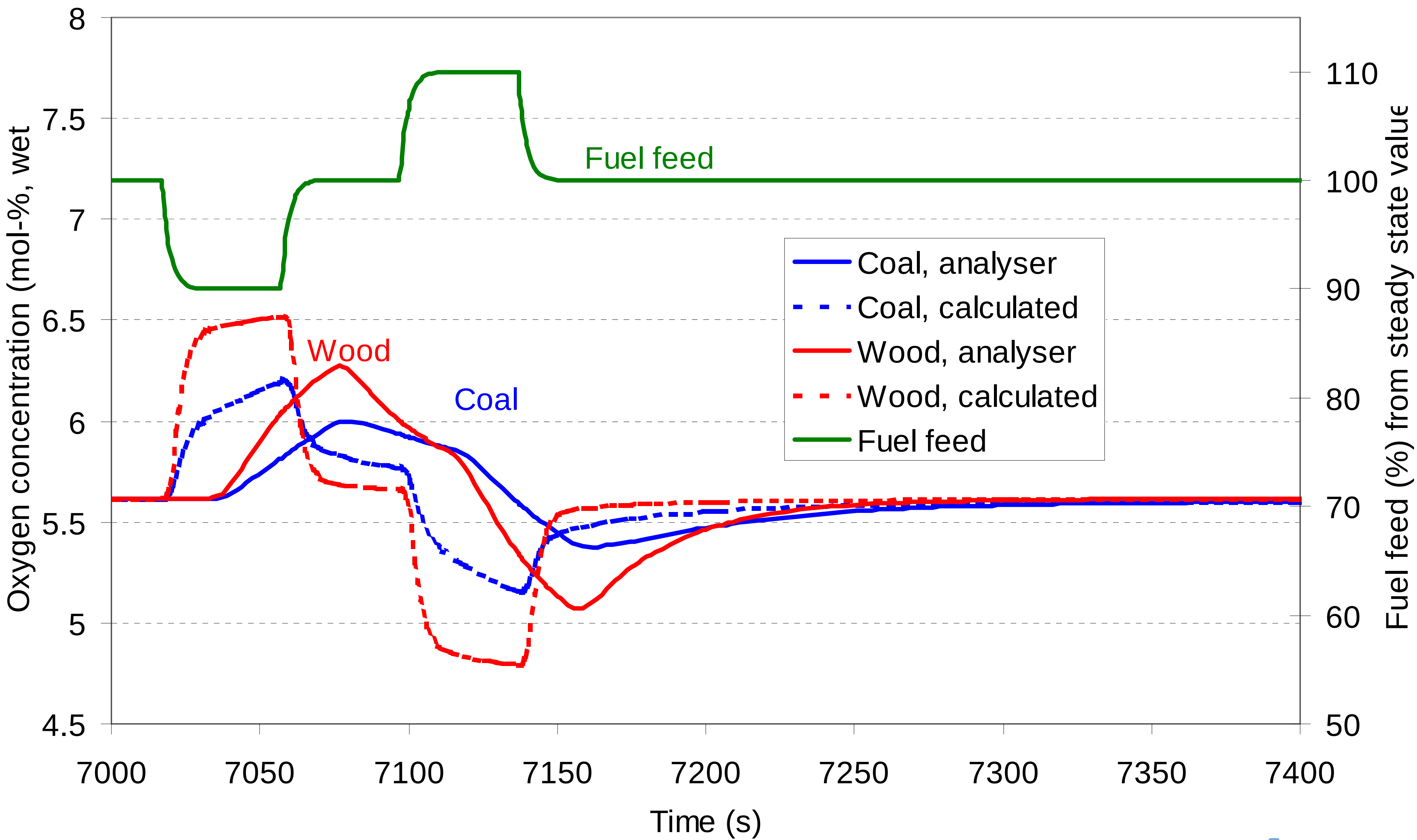
Population balance of solid materials

Fragmentation, attrition, agglomeration

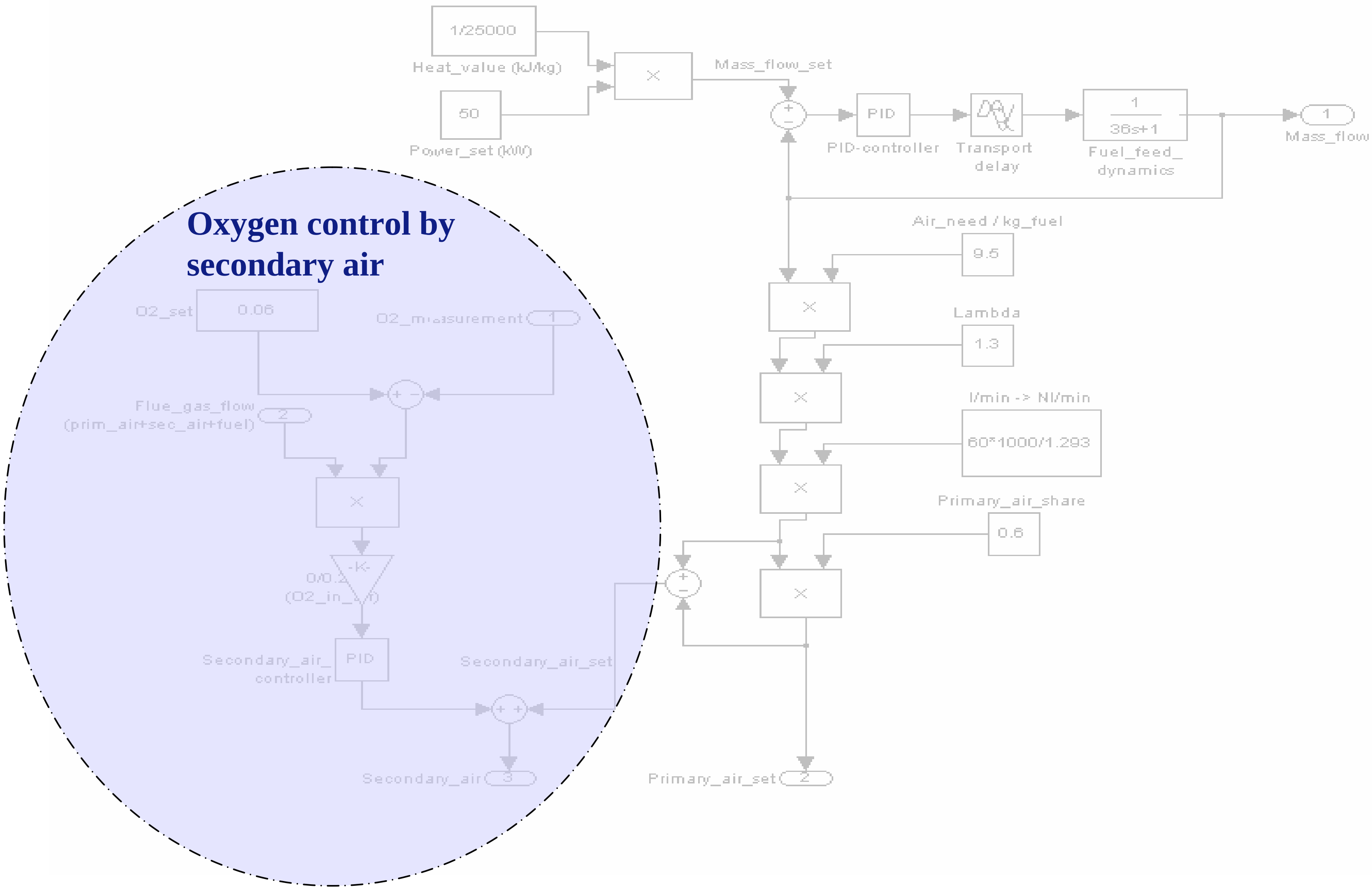
Burning profiles



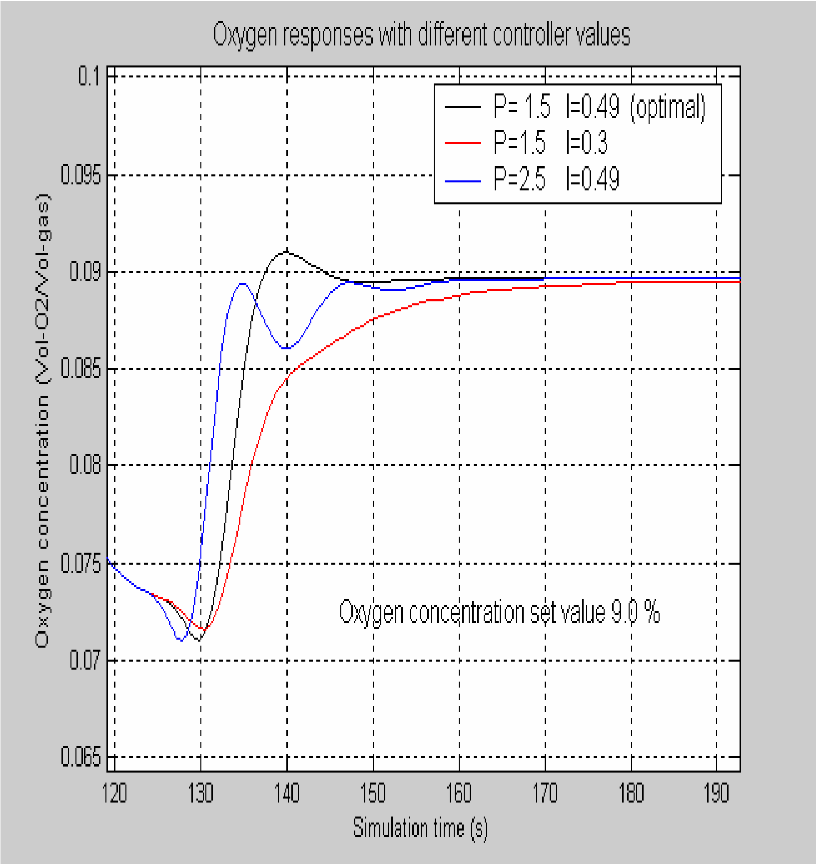
OTSC CFB control system

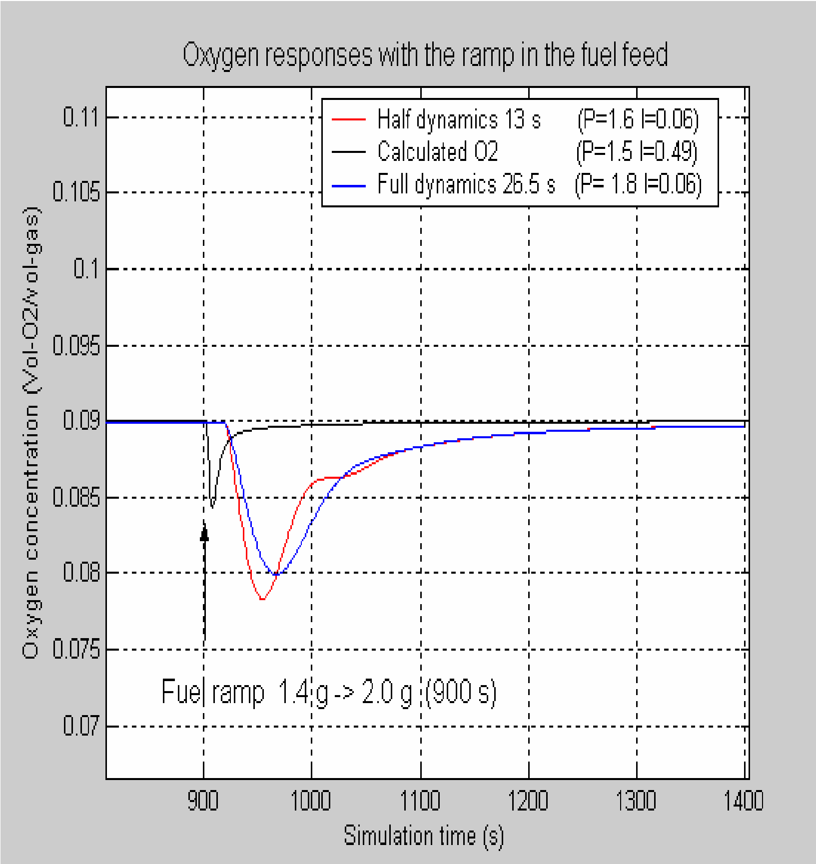

Oxygen concentration (mol-%, wet
Fuel feed (%) from steady state value
Time (s)
Fuel feed
Wood
Coal
Coal, analyser
Coal, calculated
Wood, analyser
Wood, calculated
Fuel feed
8
7.5
7
6.5
6
5.5
5
4.5
110
100
90
80
70
60
50
7000
7050
7100
7150
7200
7250
7300
7350
7400

Simplified overall control system for pilot CFB reactor

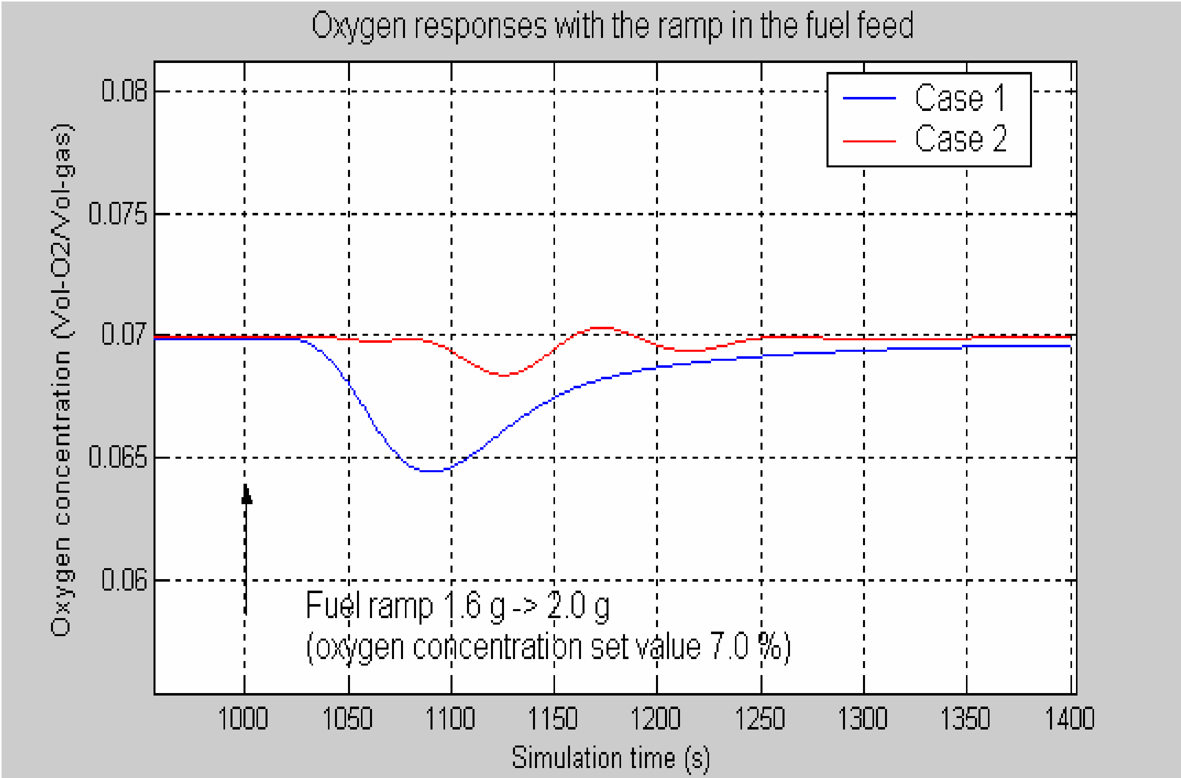


Adjustment of oxygen control (by secondary air) and effect of O_2 measurement dynamics on optimal control system





Oxygen control by secondary air compared to simplified overall control system



Case 1: Oxygen control by secondary air

- closed-loop control for O_2 by secondary air

Case 2: Simplified overall control system

- open-loop control for total air by fuel feed

+

- closed-loop control for O_2 by secondary air

Advanced control methods

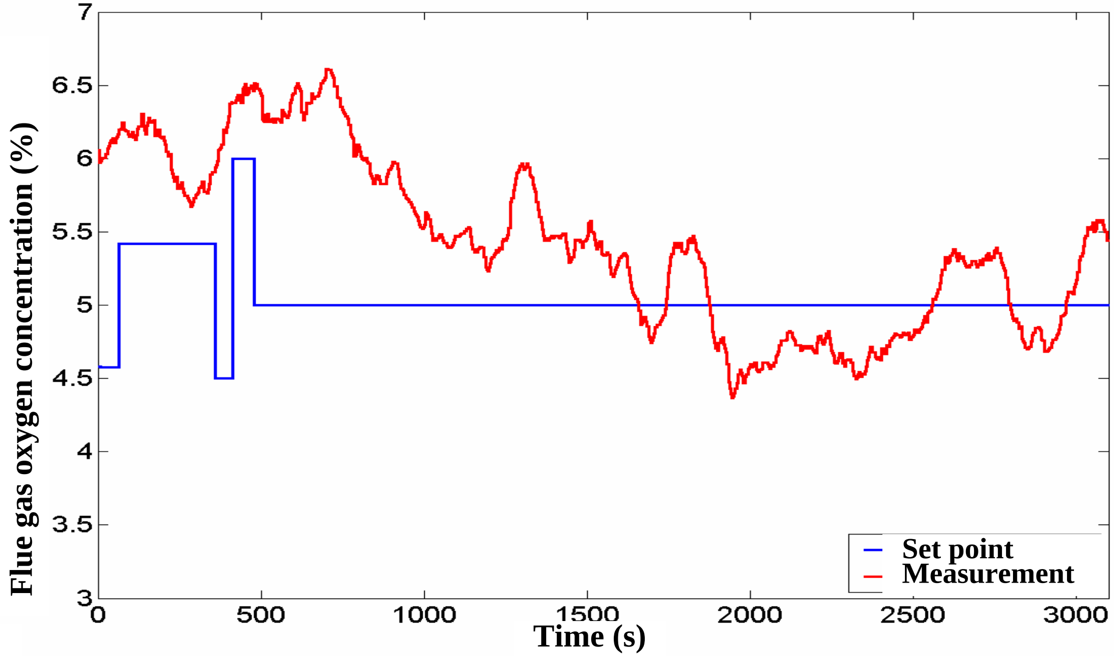
When fuel is introduced into furnace then control system must take care of stable combustion process (fuel power - steam enthalpy - electric power). Variations in pressure, flue gas oxygen concentration etc. lower efficiency, increase emissions, reduce lifetime of structures etc.

Controls are developed by using advanced control methods (GPC, Smith-predictor) combine with adaptive control approach. Also new as well existing measurements will be utilized more powerful.

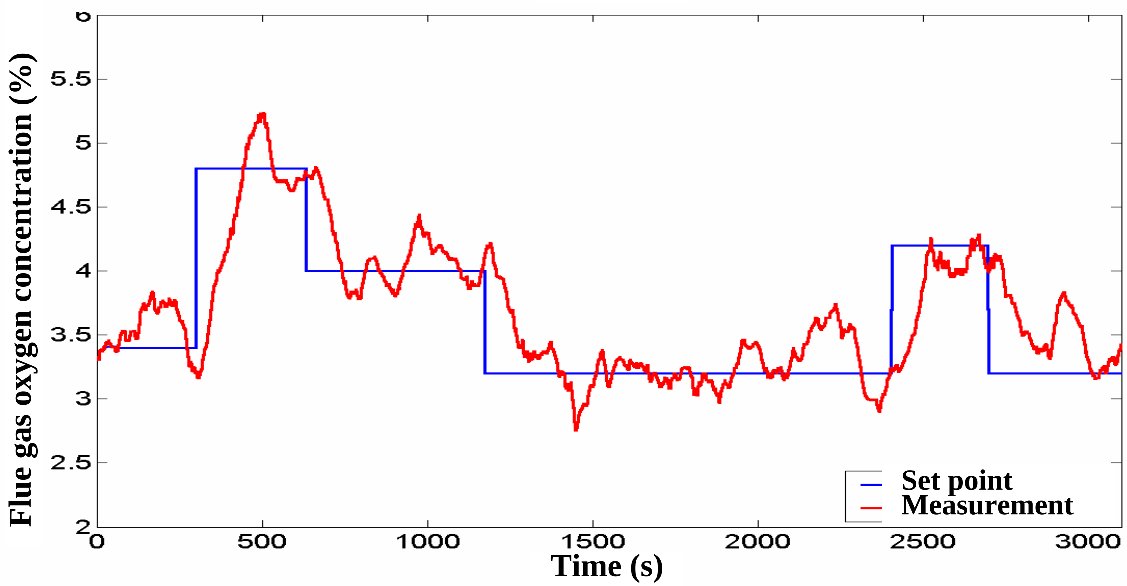
- moisture and CO_2 concentration in flue gas → adaptation (fuel quality changes)
- heat transfer probes → changes in combustion (e.g. heat transfer control in load changes)
- furnace pressure → faster response (than e.g. flue gas oxygen concentration)

Oxygen control by secondary air feed at full scale plant

Before adjustment

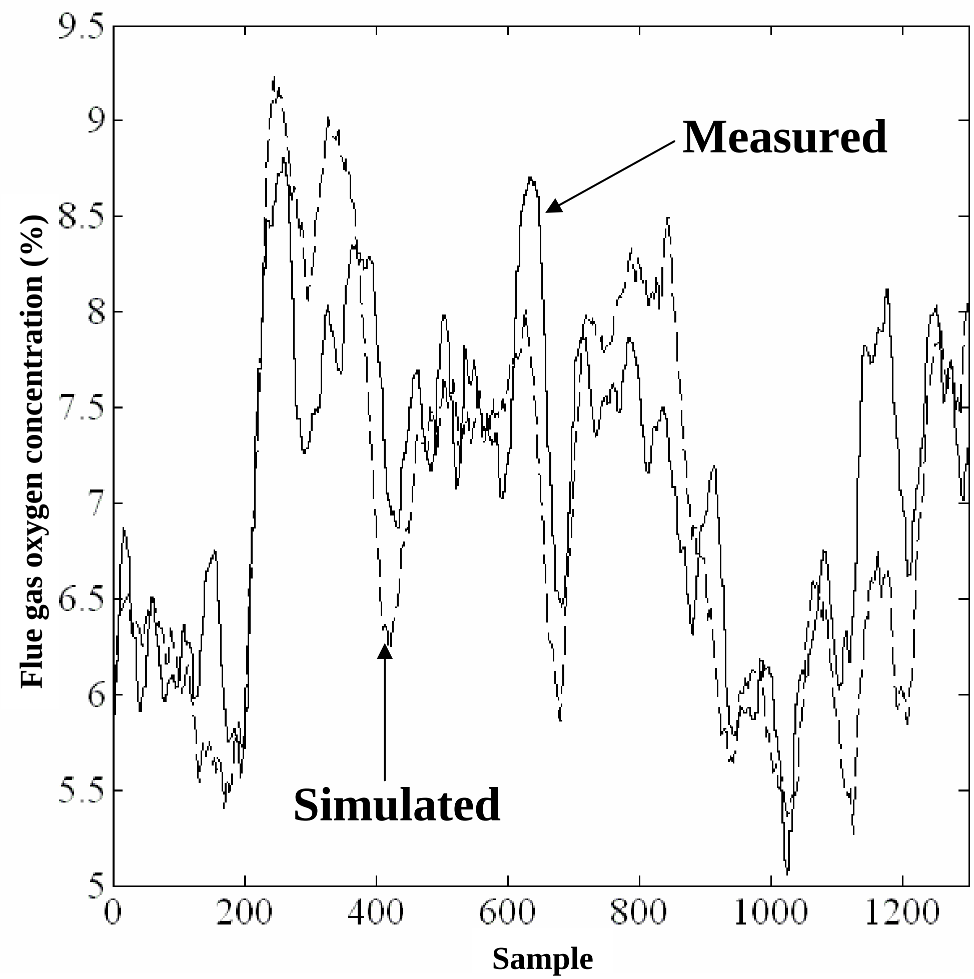


After adjustment

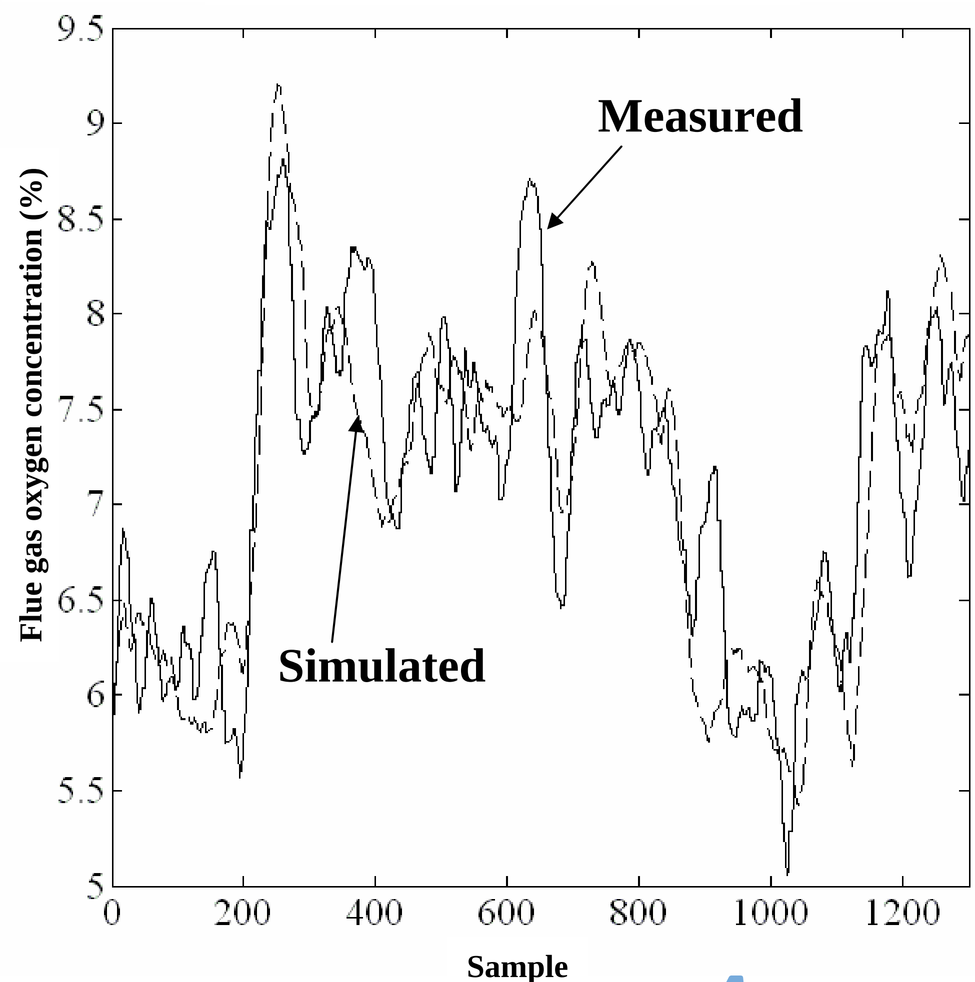


Example of adaptation

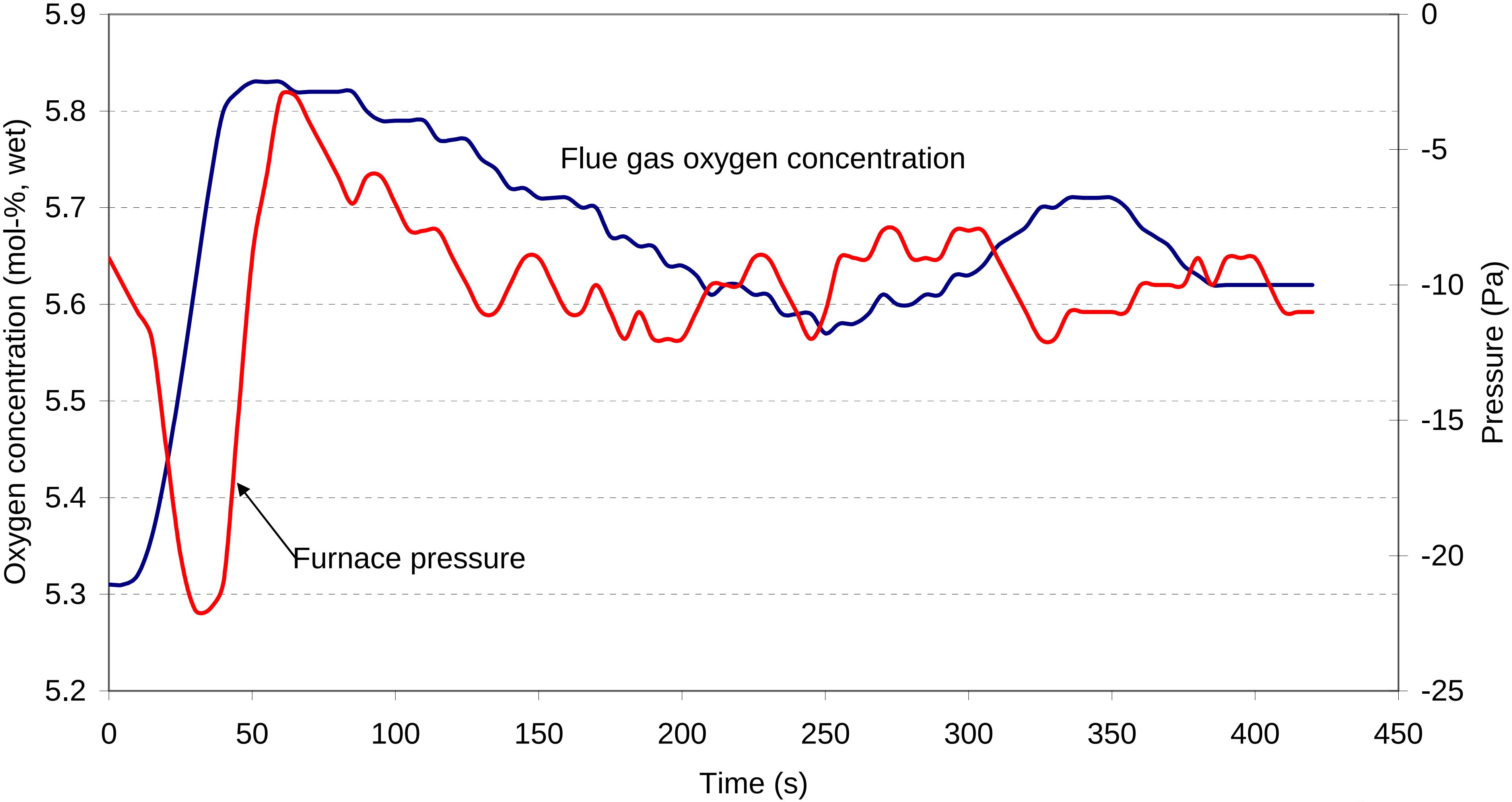
without adaptation



with adaptation



Responses for the furnace pressure and flue gas oxygen concentration during step changes in fuel feed



Signal processing tool and analysis of process measurements

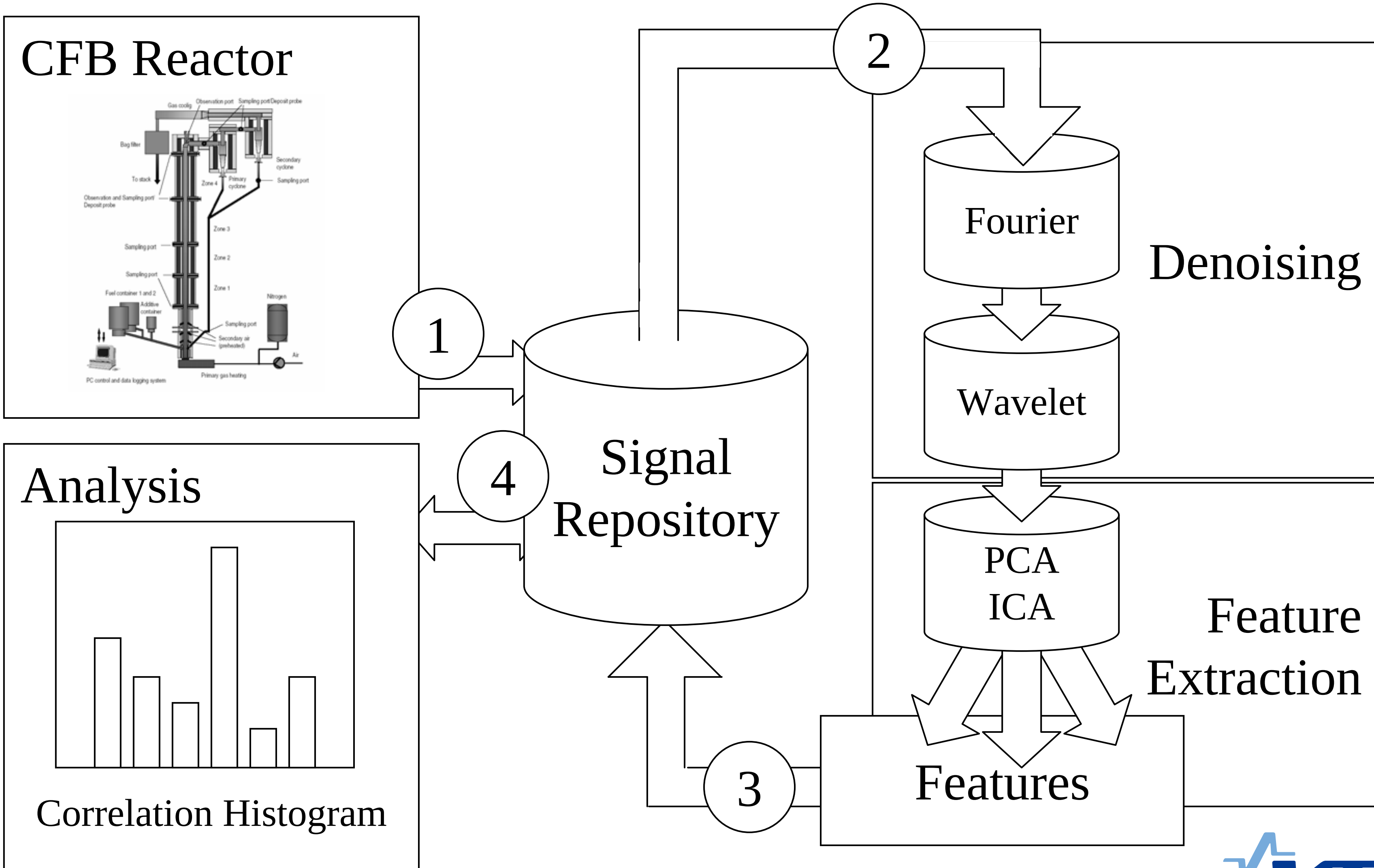
- Lot of measurements which are analysed only after alarms
- Information of the process measurements is not fully utilized
- There is lot of in formation that can be extracted from process measurements by utilizing possibilities of different signal processing methods
- Process optimisation requires performance analysis for each sub processes and further for each process measurements. Optimal limits must be set for process measurements.

→ There is need for process analysis tool

Signal processing tool and analysis of process measurements

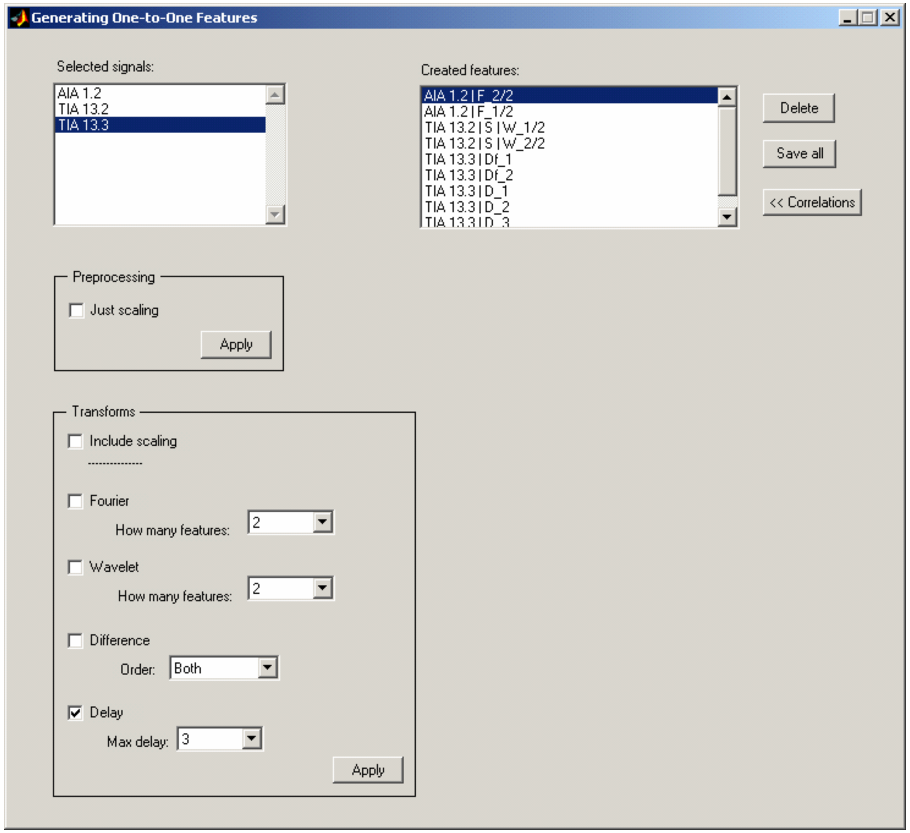
- The software provide signal monitoring, denoising and dependency detection. Also feature extraction is enabled in case the original signals cannot provide sufficient information.
- The huge amount of signal data sets challenges for data visualization also.
- The prototype enable signal monitoring, denoising, feature extraction and dependency detection via a graphical user interface.
- The final software should be compatible with commercial software and stable enough to provide reliable information on signal dependencies. Also ways for automating the signal processing task will be explored (manual configuration could be too complex or too slow in dynamic process).

Phases of Signal Processing

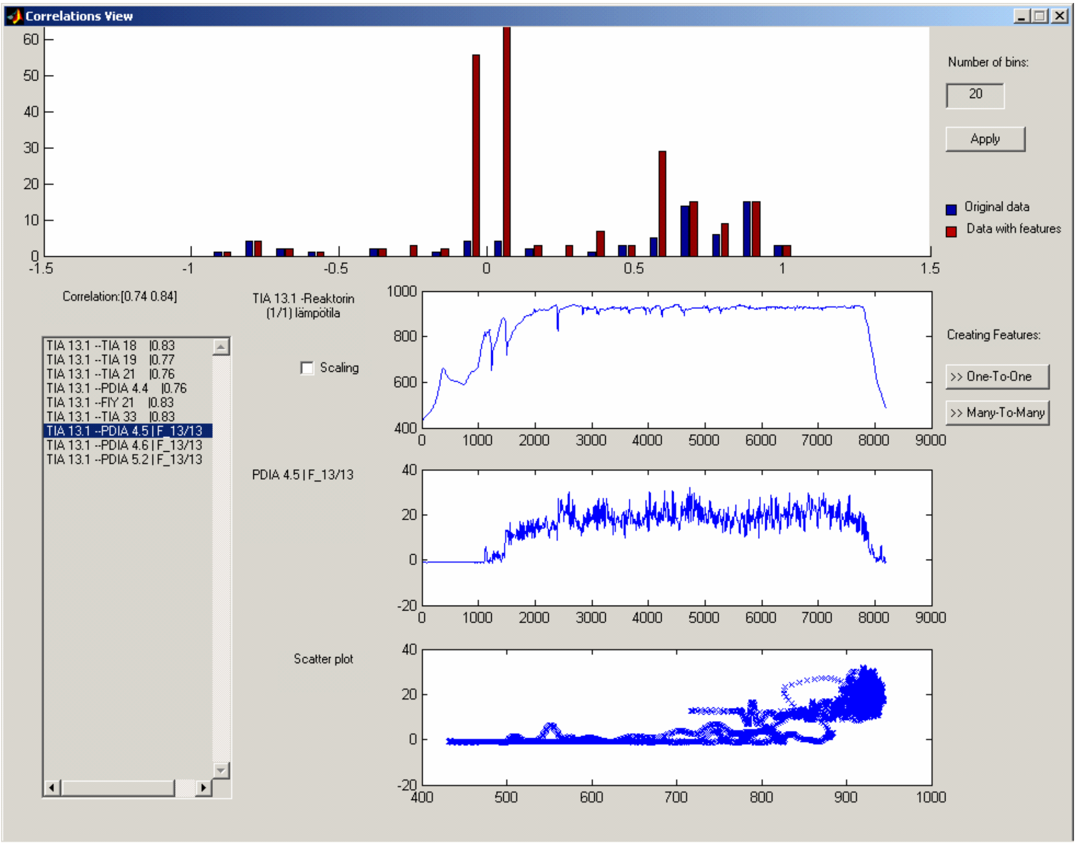


User interface for signal processing prototype

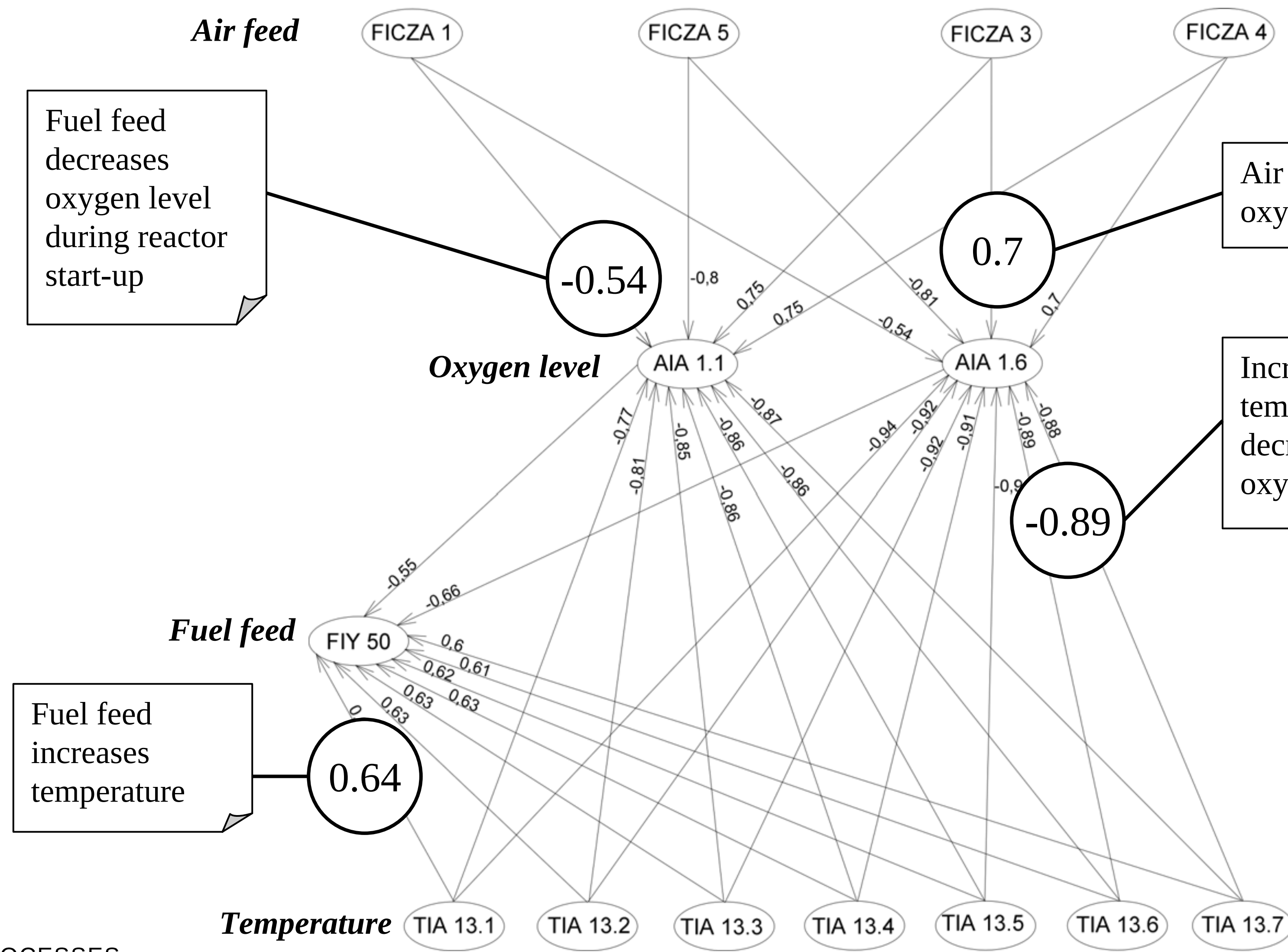
Feature extraction



Correlations between features and original measurements



Example of Correlating Signals



Conclusions

- Process development (OT), fuel selection and power production at deregulated energy markets set new demands for CFB boiler control
- There is need for testing environment to enhance control system development
- New signal processing methods and tools enhance process development and further control system development → lot of new information and correlations can be extracted
- Well-designed and viable controls are precondition for process optimization → lot of potentials in model based control
- Steady combustion process:
    - lower emissions
    - higher efficiency
    - increase lifetime of structures etc.