# A systematic process identification as a tool for combustion control design

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# Contents of the study

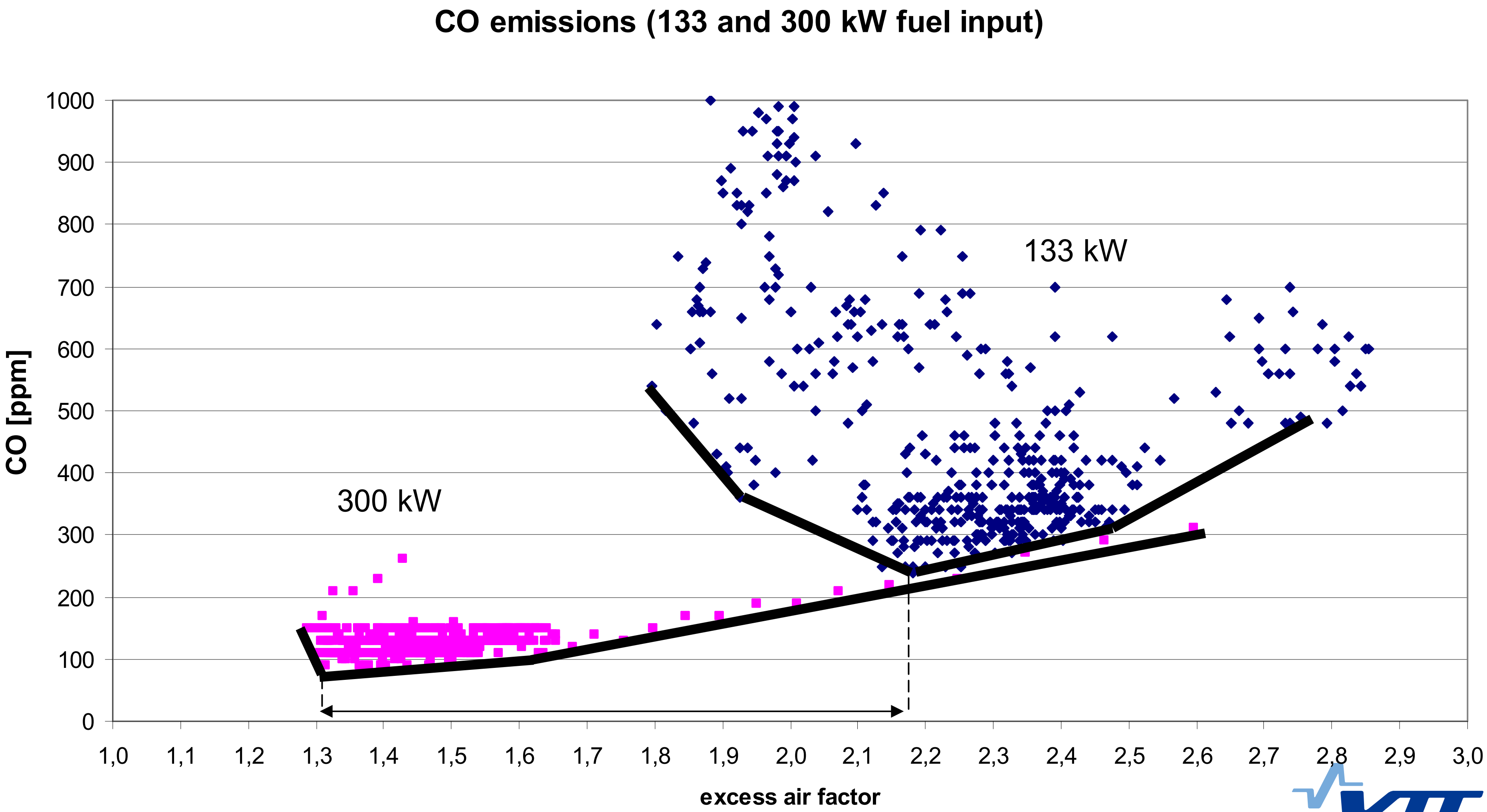
1. Preliminary tests at different operating points of the boiler
2. Systematic process identification using design of experiments
   - Control criteria
   - Identification of important control variables and disturbances, and interaction between variables
3. Step response experiments to determine dynamical behaviour of process
   - Control strategy
4. The possibility of using soft sensors to estimate important variables
   - $O_2$, $CO_2$, CO, heat output

# Test burner

- 300kW
- Fuel: wood chips
- Fuel feed: 2 screws
- Air feed: 3 fans

# Some results of the preliminary tests

## Case: a 300 kW boiler, fuel: wood chips



# Identification of important variables

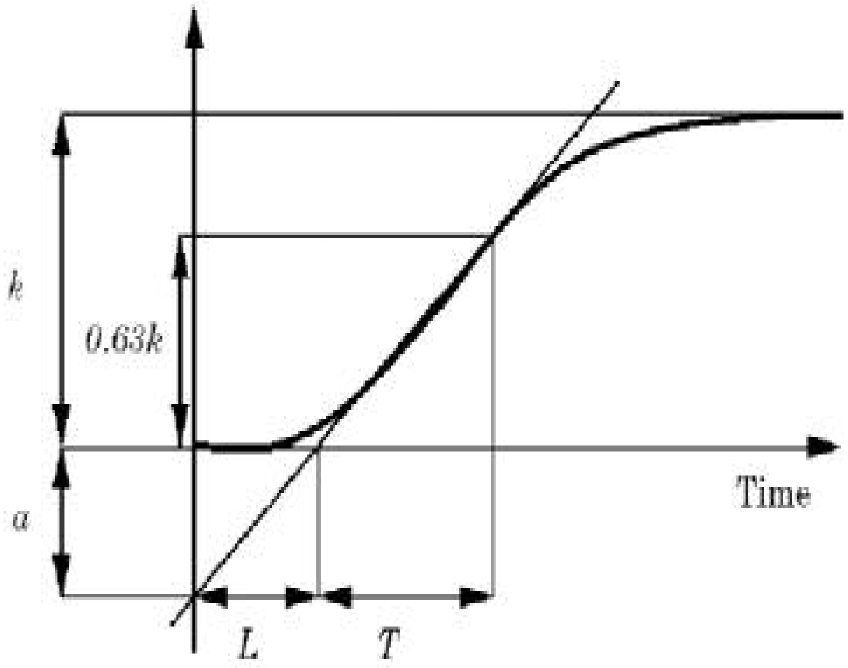
Case: a 300 kW boiler, fuel: wood chips

- $2^{k-1}$ fractional factorial design of experiments
- Fuel moisture, fuel power, total air feed, primary and secondary air ratio
- Each variable was tested on 2 levels
- Center point tests were made before and after the tests to define time variance of the boiler during test period
- Results:
  - No drifting in process parameters during tests
  - Primary/secondary air ratio has most effect on CO emissions
  - Heat output can be controlled with fuel power
  - Total air feed and fuel power control the $CO_2$ concentration in fluegas

# Step response tests

## Case: a 300 kW boiler, fuel: wood chips

- The dynamics of the boiler were defined using 1st order transfer functions
- Tests were made in three operating points to find the nonlinearities in the process
- Also steps were made in both directions



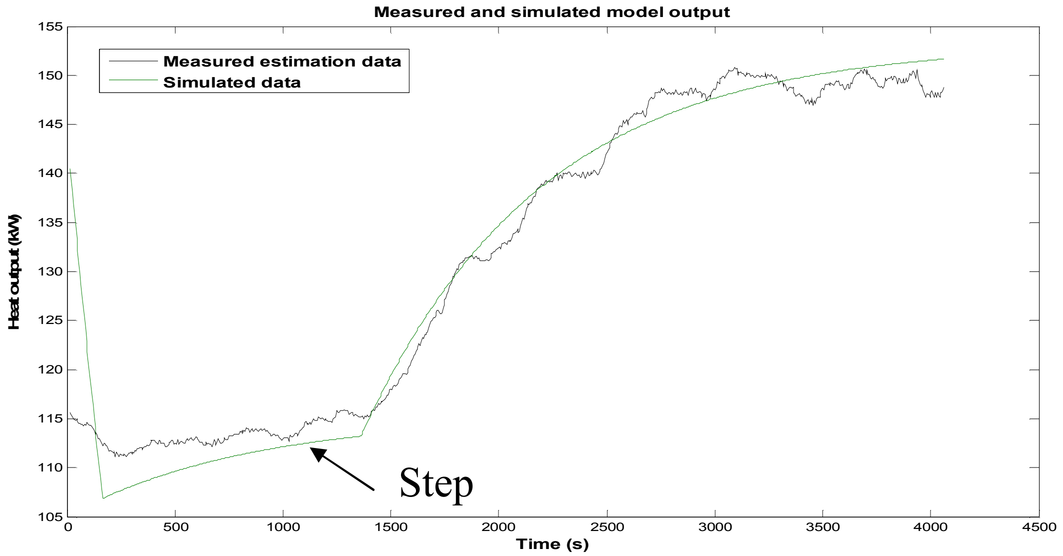

$$G(s) = \frac{Y(s)}{U(s)} = \frac{k}{1+sT} e^{-sL}$$

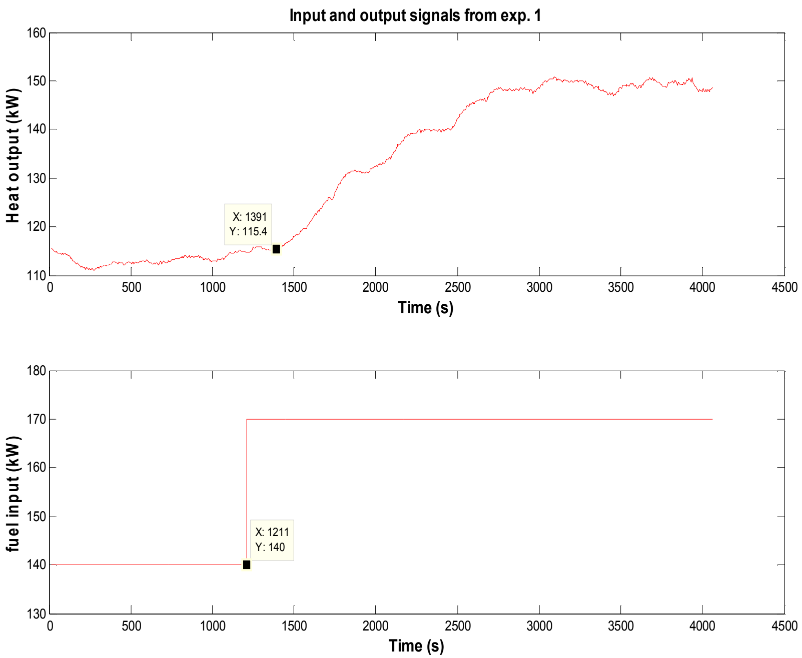
Y is output of the process
U is input of the process
L is dead time (delay)
T is time constant
k is static gain of the process

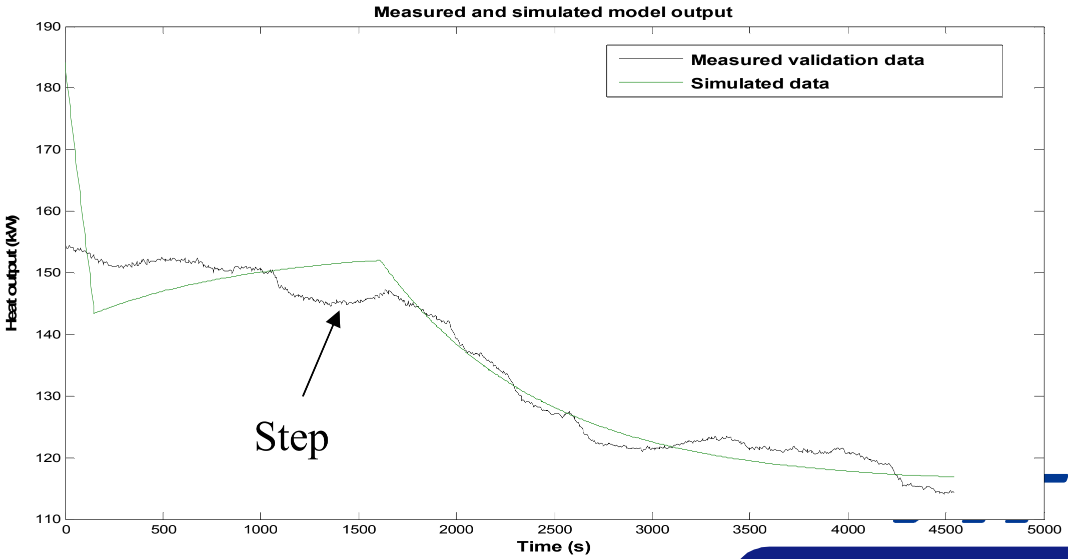
# Some results of the step response tests

## Response of the heat output to the step change of fuel power

- 30 kW change in fuel power
- Effect in heat output
  - k=1,27
  - T=827 s
  - $T_d$=150 s



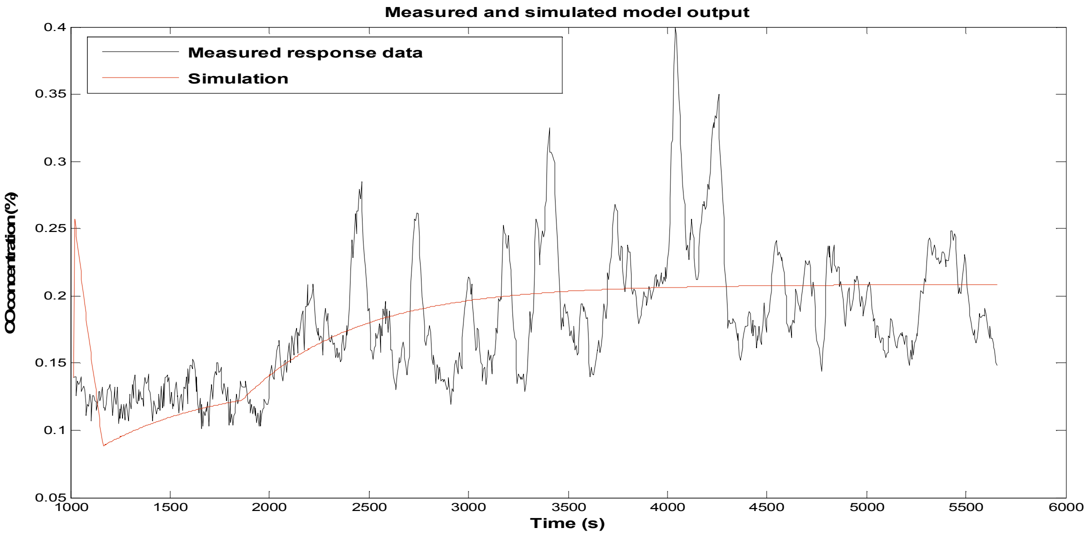



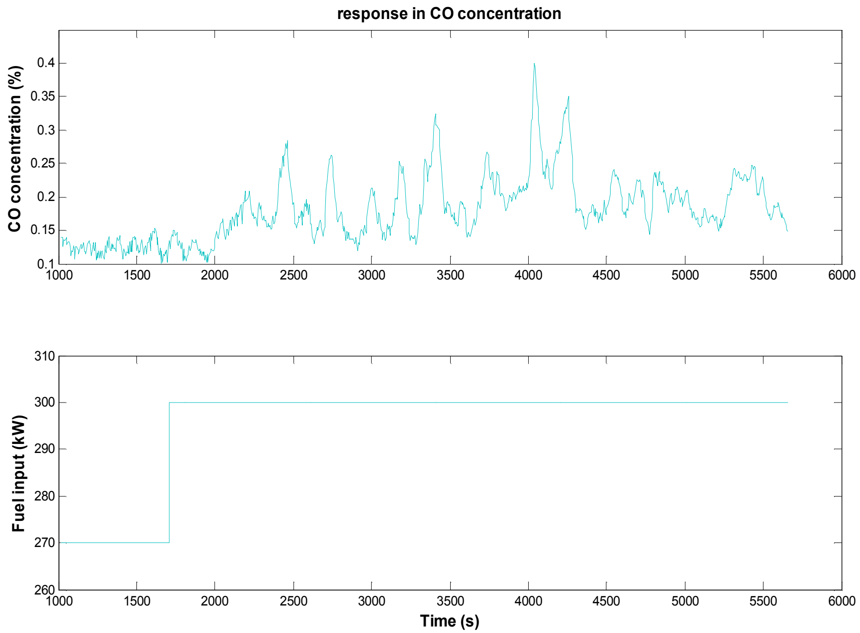



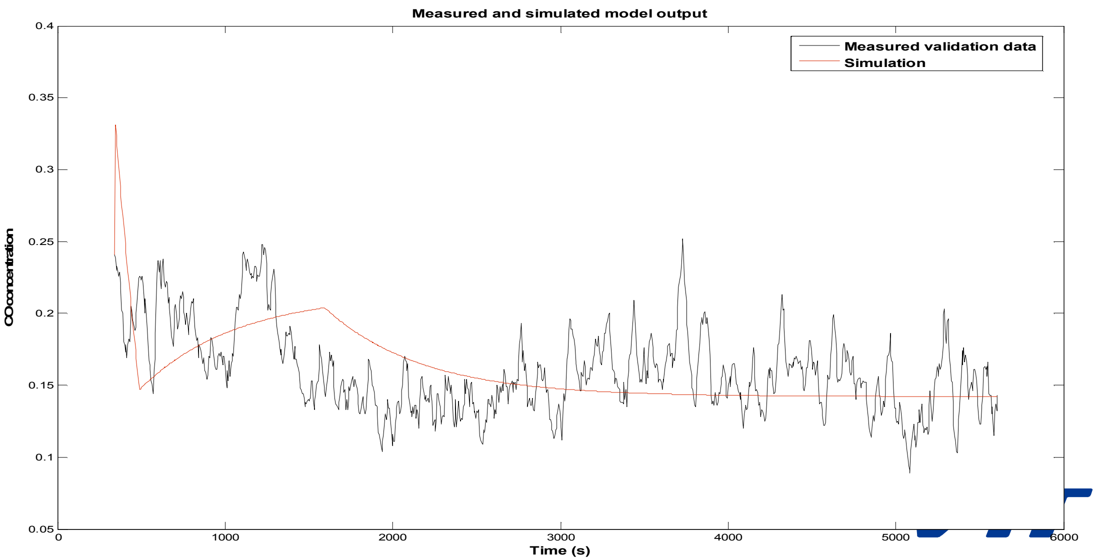
# Some results of the step response tests

## Response of the CO concentration to the step change of fuel power

- 30 kW change in fuel power
- Effect in CO
  - k=0,002
  - T=577 s
  - $T_d$=149 s



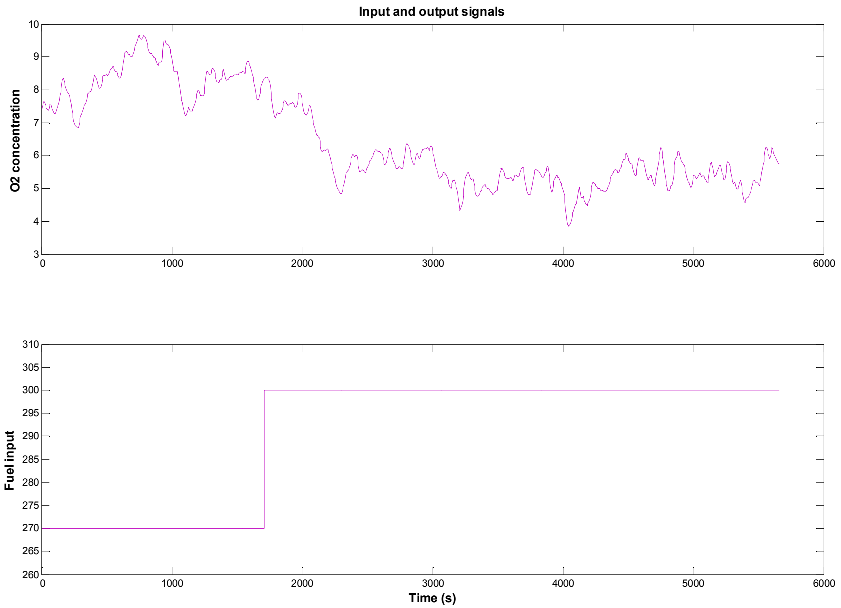



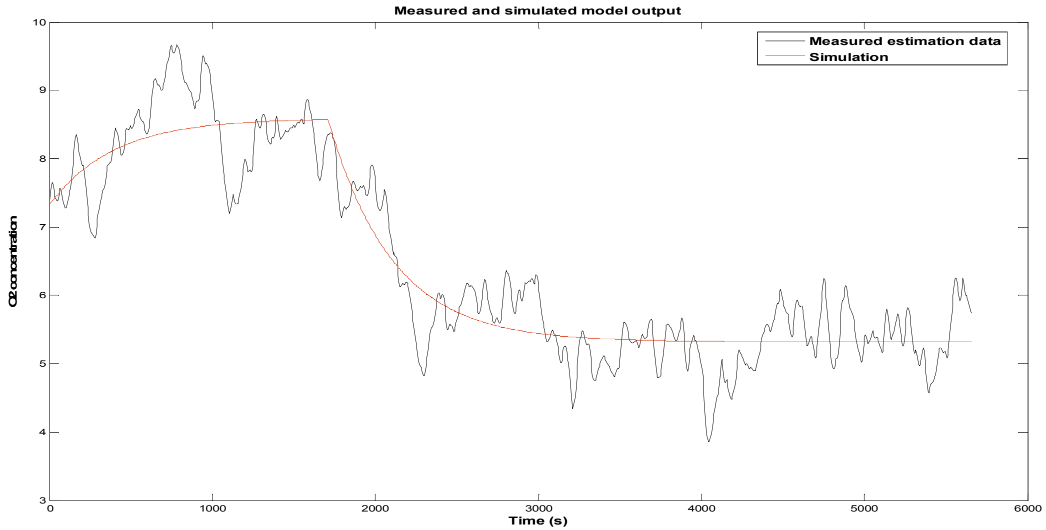



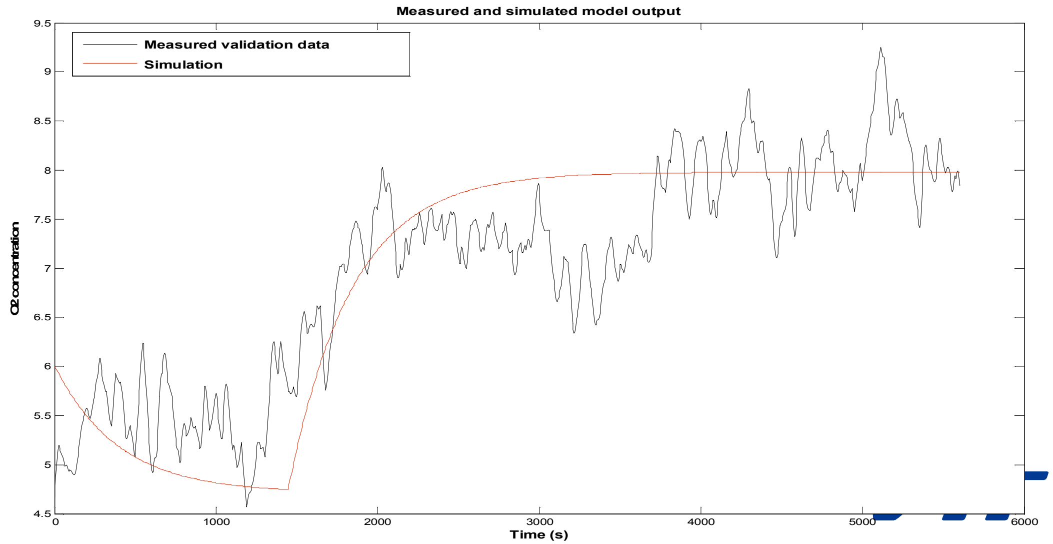
# Some results of the step response tests

## Response of the $O_2$ concentration to the step change of fuel power

- 30 kW change in fuel power
- Effect in $O_2$
  - k=-0,109
  - T=393 s
  - $T_d$=0 s



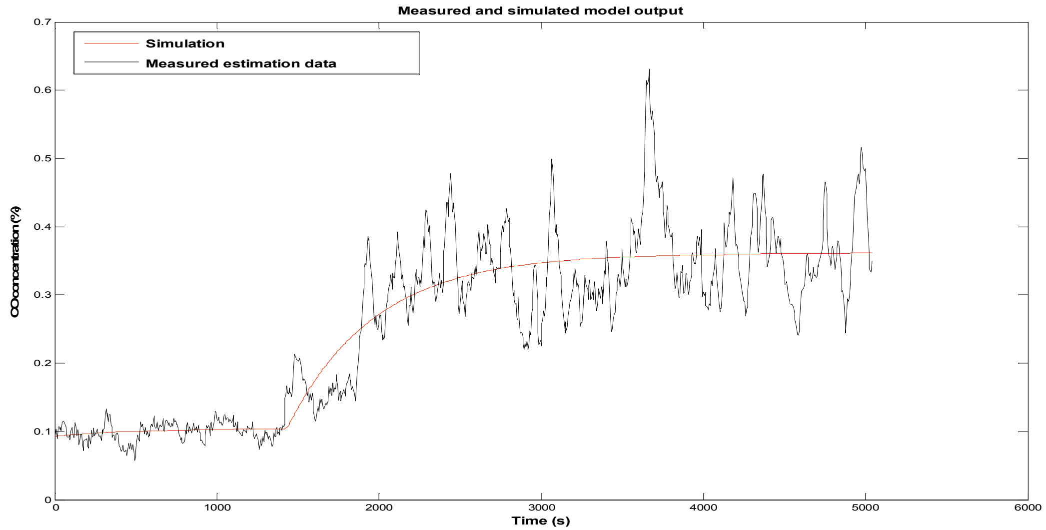



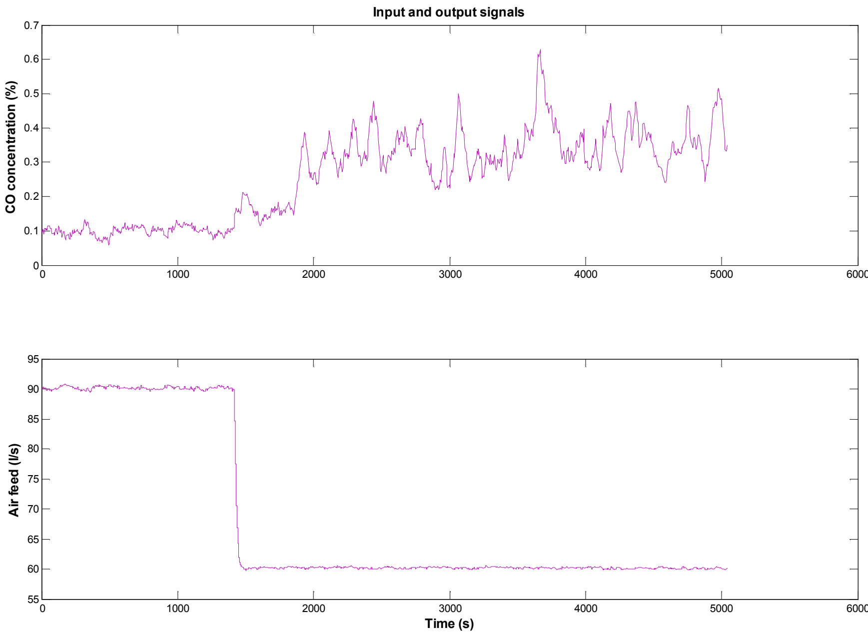



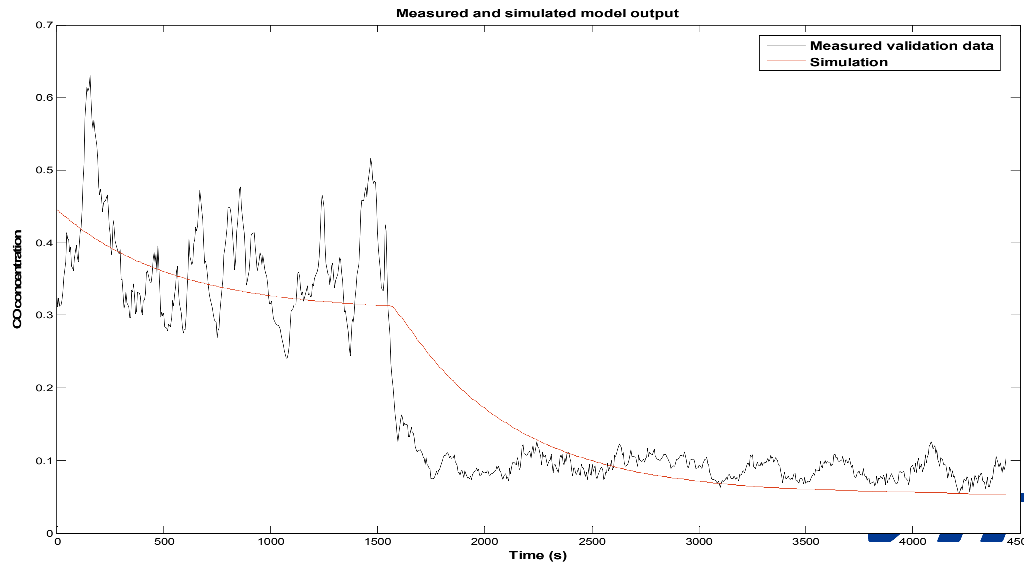
# Some results of the step response tests

## Response of the CO concentration to the step change of total air feed

- 30 l/s change in total air feed
- Effect in CO
  - k=-0,009
  - T=537 s
  - $T_d$=0 s



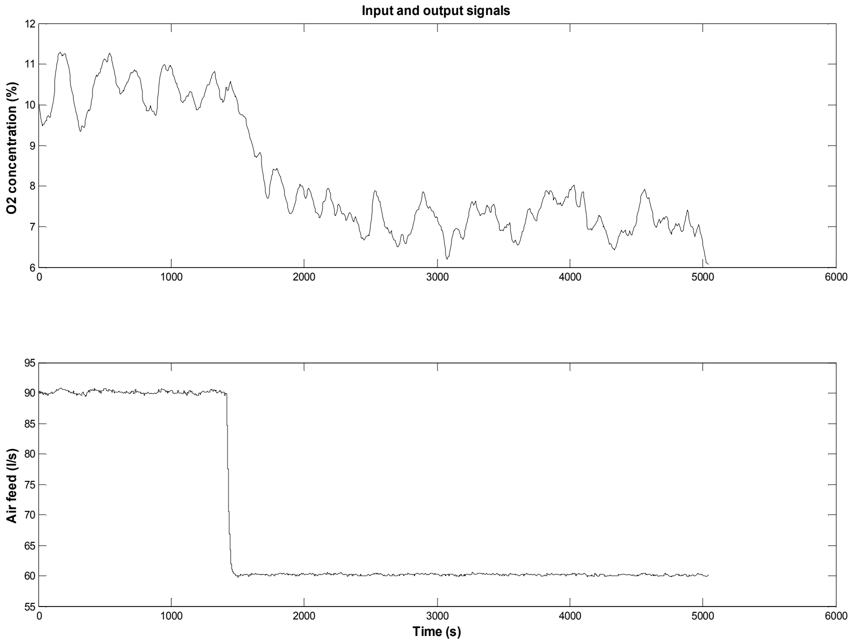



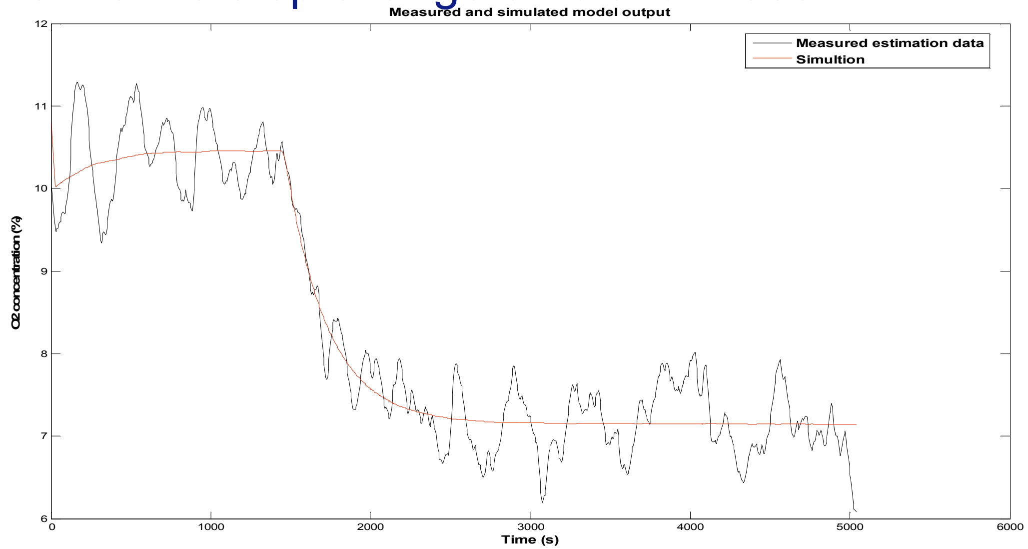



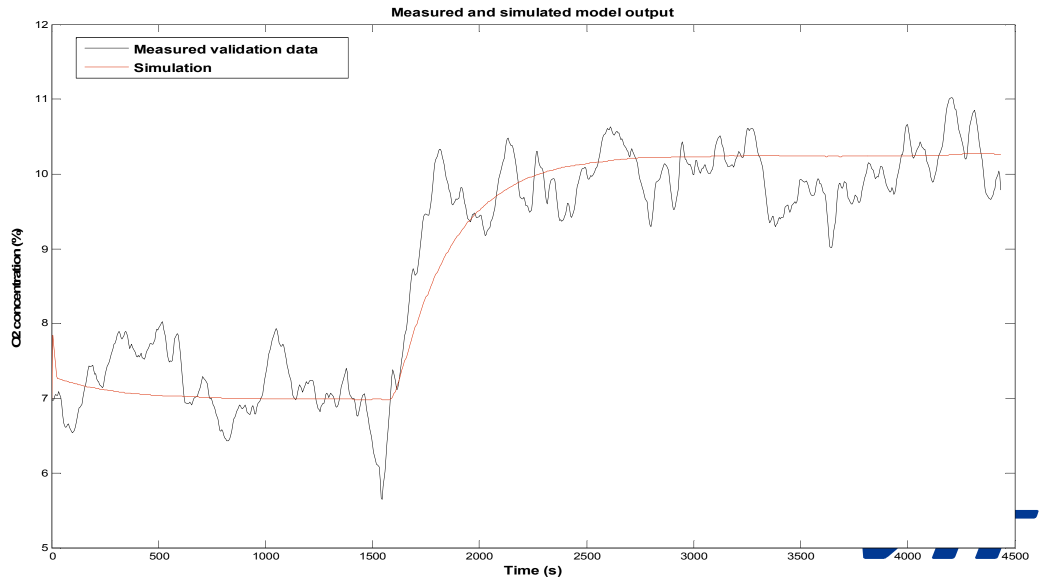
# Some results of the step response tests

## Response of the $O_2$ concentration to the step change of total air feed

- 30 l/s change in total air feed
- Effect in $O_2$
  - k=0,111
  - T=263 s
  - $T_d$=26 s



# Results of the step response tests

## Case: a 300 kW boiler, fuel: wood chips

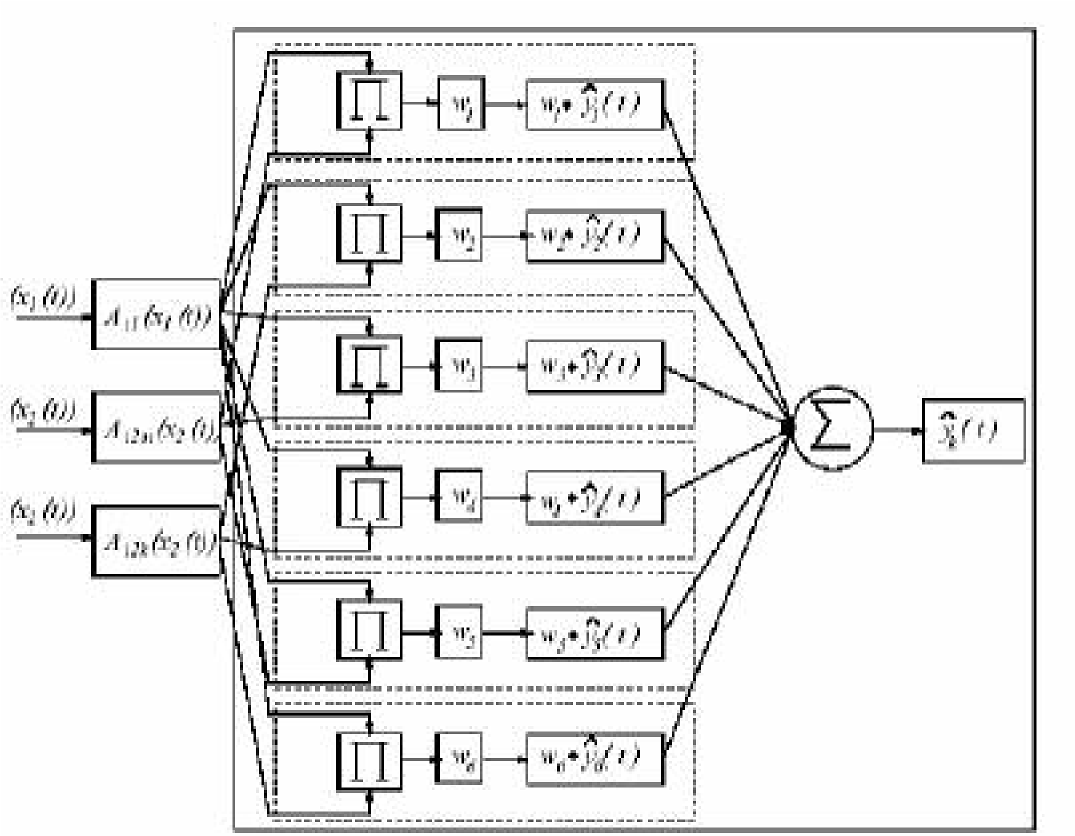
- The behavior of this boiler can be simulated with first order transfer functions
- Separate models have to be created for different power levels (operating points)
- Changes in fluegas components were faster when air feed was increased or fuel feed was decreased
- Heat output behaved the same way in both directions

# Soft sensors

- Mika Ruusunen, University of Oulu

- Usually mathematical model(s) of process variables
- Utilisation of simple sensors, sensor fusion
  - Fast response, inexpensive, reliability
- Models developed in this research are based on the Takagi-Sugeno fuzzy model
  - Utilisation of expert knowledge
  - Local linear models for changing operation conditions

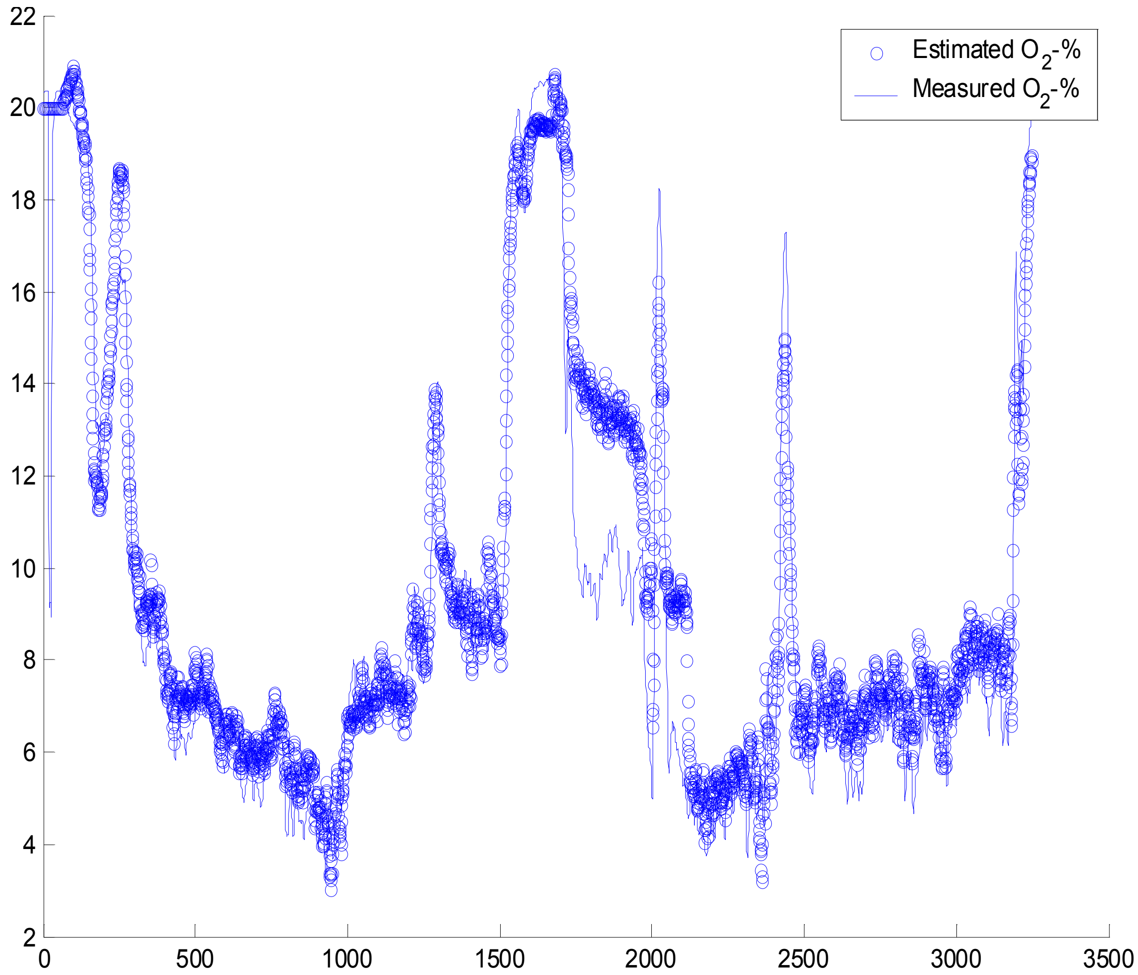
# Takagi-Sugeno Model Structure



- R1: IF x1 is {Ai1} AND x2 is {Ai2n} THEN y1 = **a**1 **x** + b1
- R2: IF x1 is {Ai1} AND x2 is {Ai2k} THEN y2= **a**2 **x** + b2

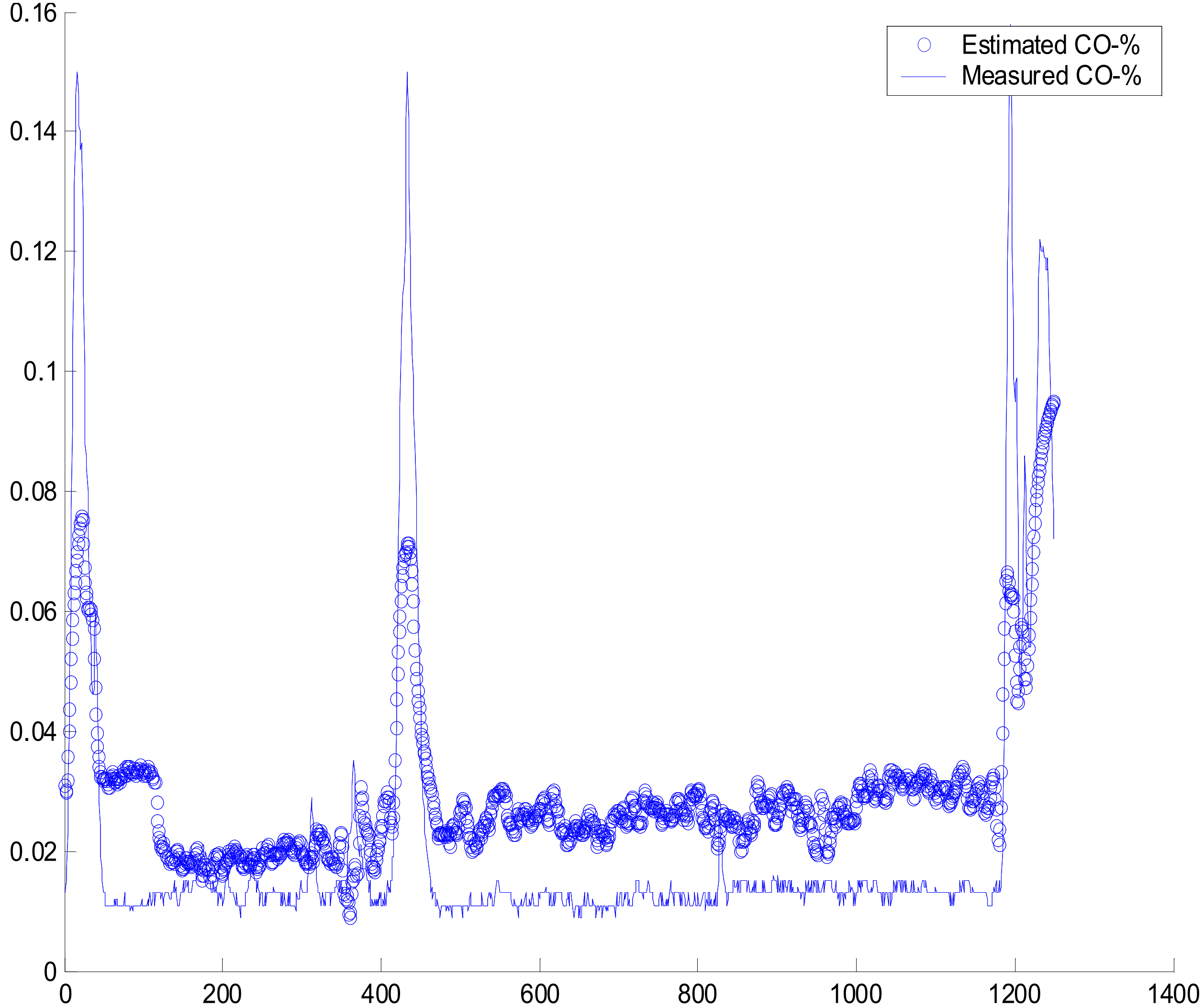
# Monitoring of flue gas O2 vol.-%

## Case: a 300 kW boiler, fuel: wood chips



# CO-monitoring

## Case: a 300 kW boiler, fuel: wood chips



# Conclusions

- The process was identified using design of experiments
  - CO emissions can be controlled with primary/secondary air ratio and total air feed
  - Heat output can be controlled with fuel power
  - Total air feed and fuel power control the $CO_2/O_2$ concentrations in flue gas
- Step response test results
  - Local behaviour of process variables can be modelled with 1st order transfer functions
  - Separate models have to be created for different operating points
- The usability soft sensors in monitoring and control of the process was studied
  - $CO_2/O_2$ can be modelled using temperature measurements
  - CO model needs more research

# THANK YOU FOR YOUR ATTENTION!!

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