Optimization of biomass fired grate stoker systems

Sjaak van Loo, Robert van Kessel

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Introduction

The TNO mission:

To apply technological knowledge with the aim of strengthening the innovative power of industry

One field of expertise is Thermal Conversion Technology

Mathematical models are used to optimize thermal conversion processes, like:

- **Cement process**
- **Biomass gasification**
- **Biomass combustion**
- **Municipal Solid Waste Combustion**

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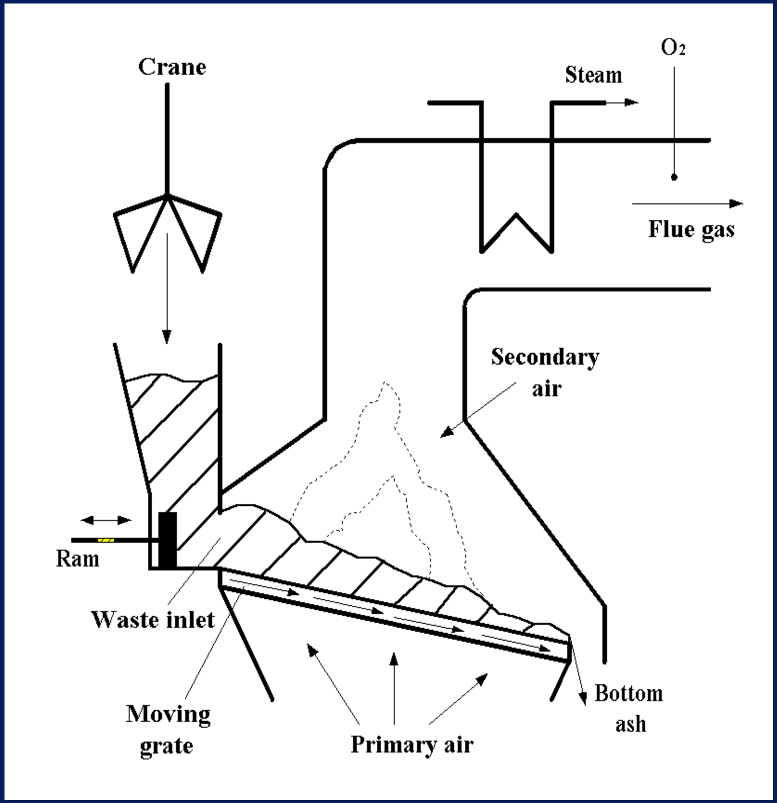
Dynamic model for grate stoker systems (1)



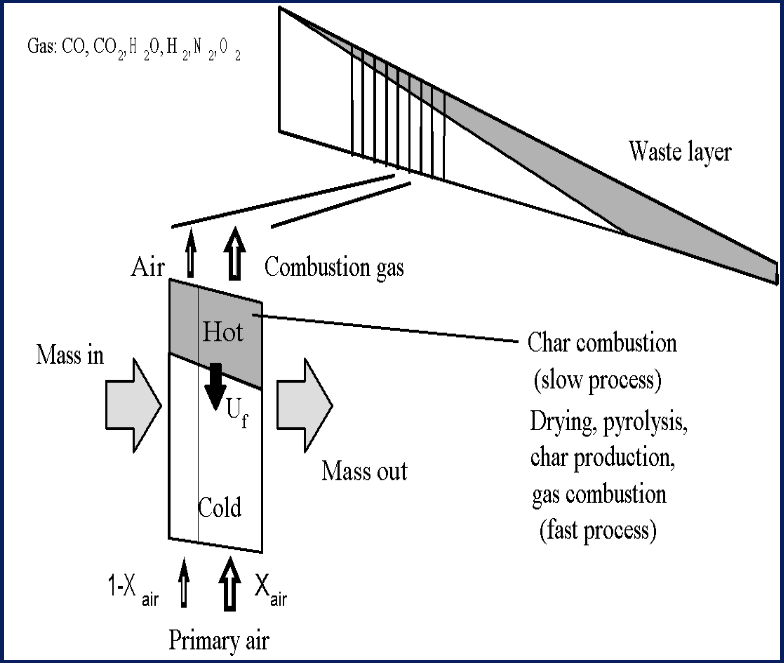
Dynamics of the furnace:

- Fuel layer
- Gas phase

and the boiler section are described

Interaction between the gas phase and the fuel layer through radiation

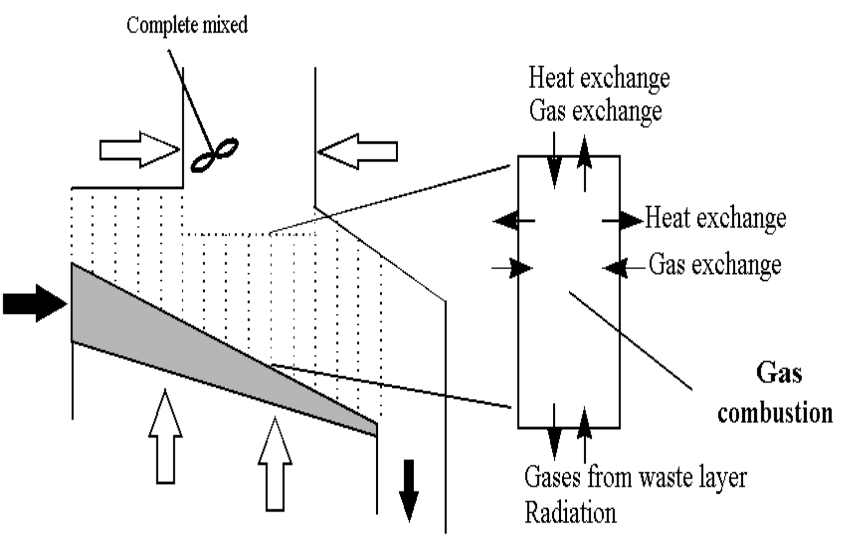
Dynamic model for grate stoker systems (2)



- The grate is divided into many slices
- Mass and energy balances solved for every slice
- Conversion process:
  - Propagation of ignition front
  - Fuel layer divided in two parts:
    - Hot reacting part on top
    - Cold fresh fuel at the bottom
  - Speed of propagation front is depending upon:
    - Fuel composition
    - Amount of combustion air

Dynamic model for grate stoker systems (3)

- Geometry is included:
  - Co-current part
  - Countercurrent part
  - Ideally mixed part
- The co-current and countercurrent parts are divided into many ideally mixed gas reactors with
  - CO, H2: mixed is burnt
  - Non-ideal mixing parameter



Model validation (1)

How to validate dynamic models?

- Step response method
- System identification

System identification:

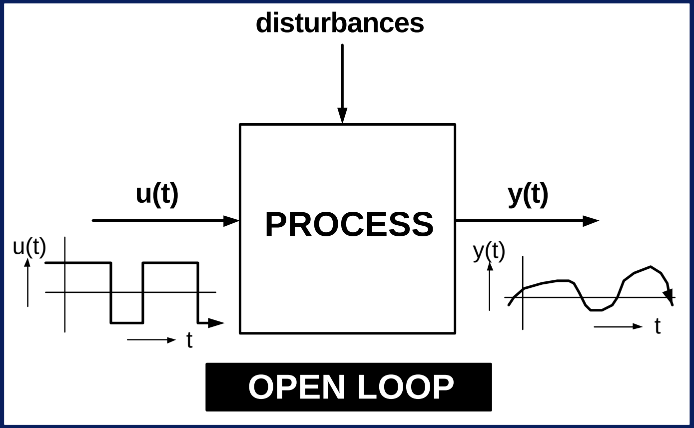
- Experimental modeling resulting in dynamic input-output relations without any physical meaning (black-box modeling)
- Can be used for MIMO systems and for closed-loop systems.

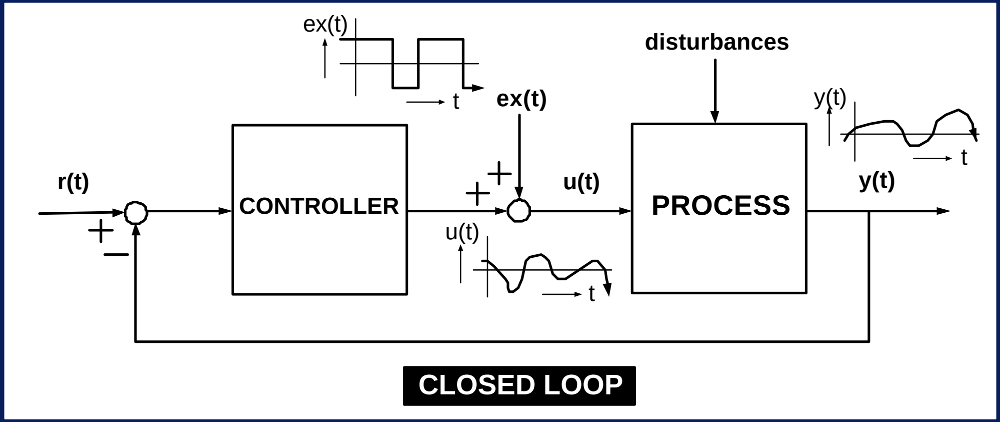
Model validation (2)

Three step procedure in system identification:

1. Experimental phase

excitation of process by user-defined signals + collection of in- and output data u(t) resp. y(t), t=1 N:





2. Estimation of a model

by minimizing the difference between the measured output signals y(t) and prediction of these output signals y*(t,parameters):

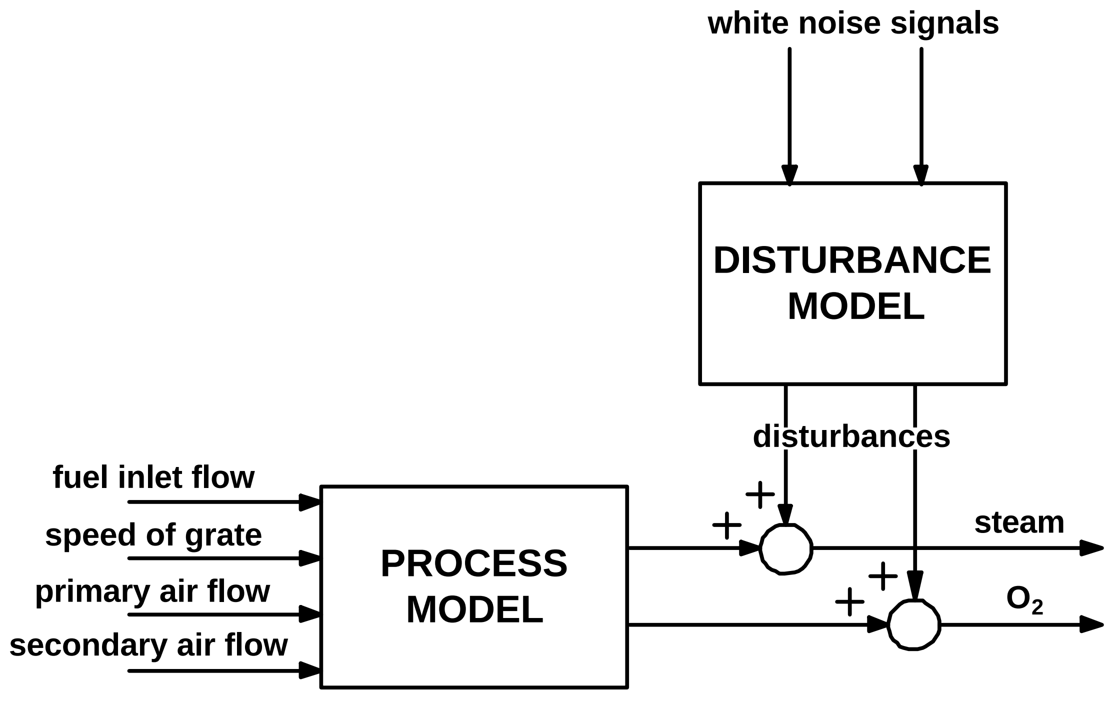
$$\min_{parameters} \frac{1}{N}\sum_{t=1}^{N}(y(t)-y^*(t,parameters))^2$$

3. Validation of the estimated model

by using, for example, statistical techniques

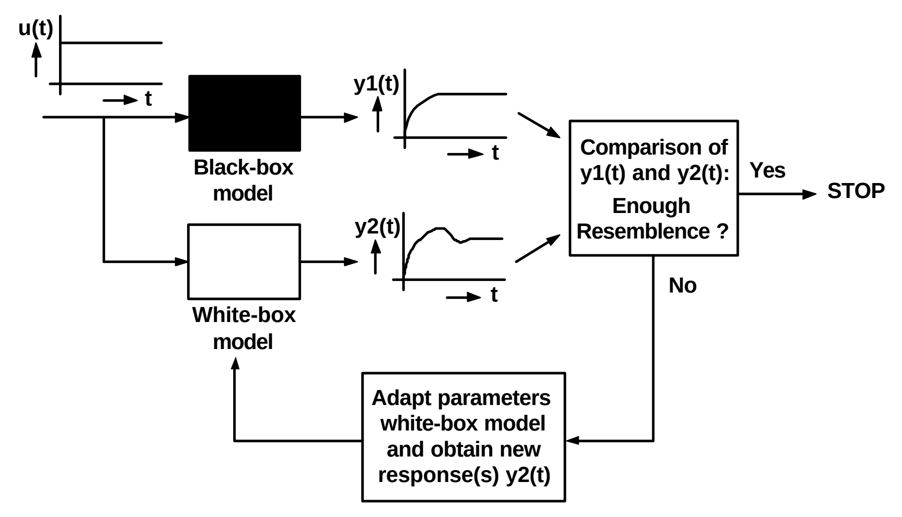
Model validation (3)

System identification results in a separated process and disturbance model:



Model validation (4)

Validation first-principles model by means of the estimated model:



u(t)

t

Black-box model

y1(t)

t

White-box model

y2(t)

t

Comparison of y1(t) and y2(t): Enough Resemblence ?

Yes

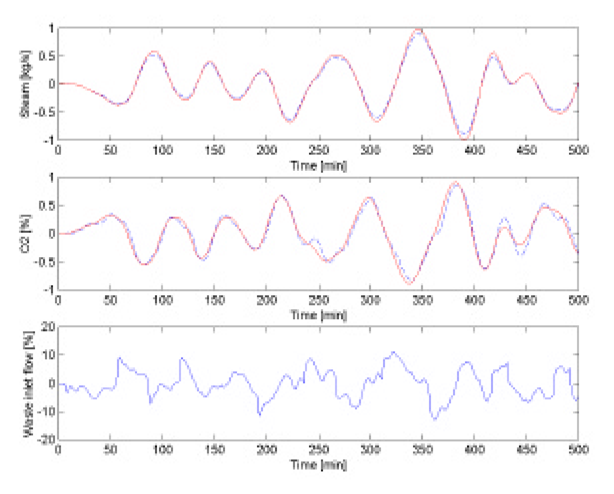
STOP

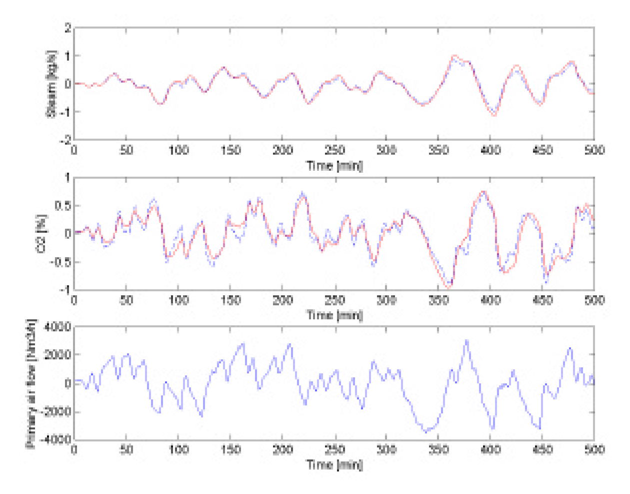
No

Adapt parameters white-box model and obtain new response(s) y2(t)

Method:

Results:





Practical application (1)

Operational experiences:

fly-ash deposition to the furnace walls, leading to reduced throughput.

high fly-ash rates due to a relative small grate and high primary air flows.

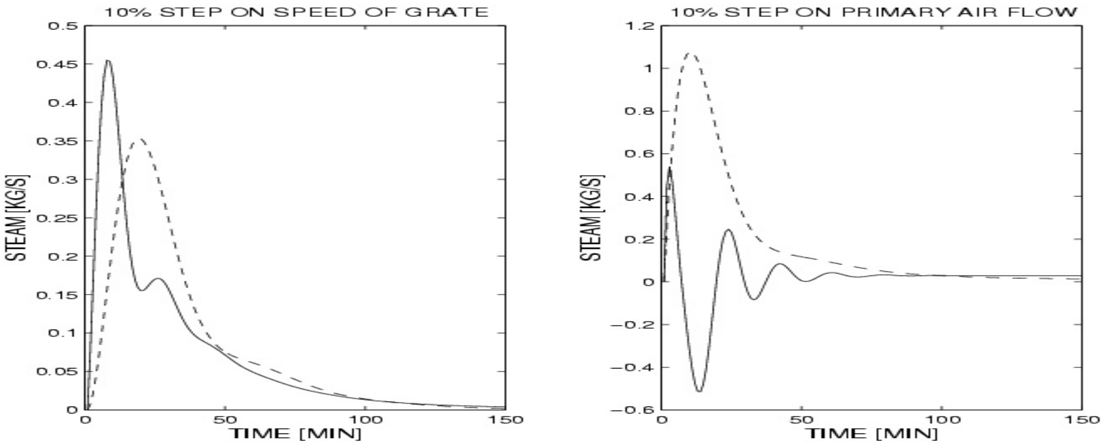
flue gas temperatures at inlet second boiler pass fairly high, causing high temperature corrosion.

no reliable combustion of low-calorific fuels.

Practical application (2)

Title:

Process analysis with system identification:



Practical application (3)

Conclusions of process analysis:

Influence primary air is bad due to excess air and wrong distribution

Grate speed is used as control variable

Control concept is not in agreement with philosophy: primary air is the best control variable

Practical application (4)

Application of TNO-simulator:

Adaptation of the model to the specific situation, including control concepts

Conclusion from simulations (1):

Very short fire, high thermal load on zones 1 and 2. The steam production can be influenced mainly with the waste flow and grate speed. The primary air has nearly no influence.

Oxygen can be controlled well with the primary and secondary air flow.

Practical application (5)

Conclusion from simulations (2):

- Present control concept is not transparent, so adaptation is needed
- Primary air distribution along the grate has to be changed

A new control concept has been developed based upon experiences with the simulator

Practical application (6)

Control objectives:

Maximal conversion (combustion) of the fuel

Maximal fuel throughput (highly flexible)

Maximal steam production/energy output

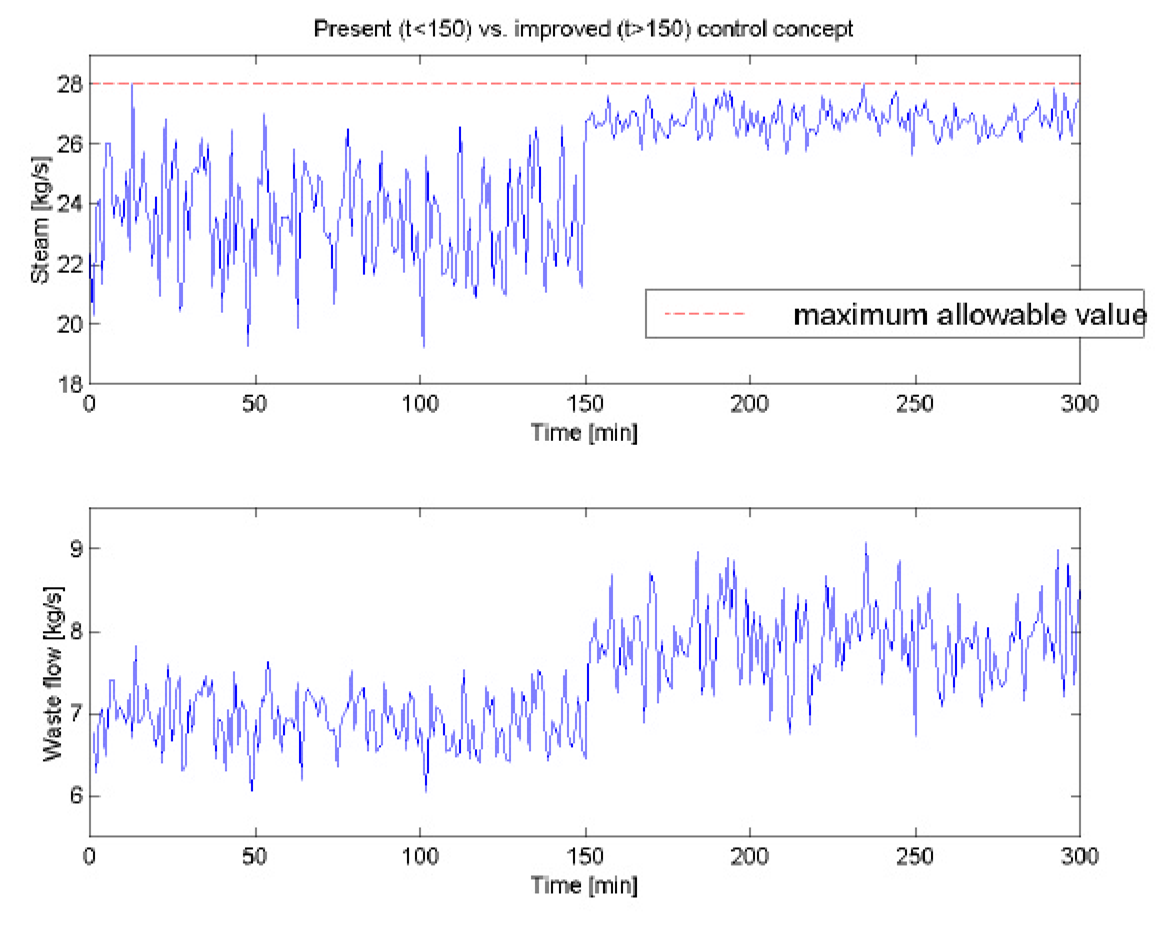
Operate below but as close as possible to the maximum levels imposed out of life span considerations

Reduce the fluctuations in the process variables due to the variation in fuel composition:

- Reduce fatigue due to variability of thermal stress
- To be able to operate more closely to constraints imposed out of life span considerations
- To reduce load on post-combustion control equipment

Practical application (7)

Results:



Control of solid fuel combustion plants (1)

Performance assessment conventional solid fuel combustion control systems:

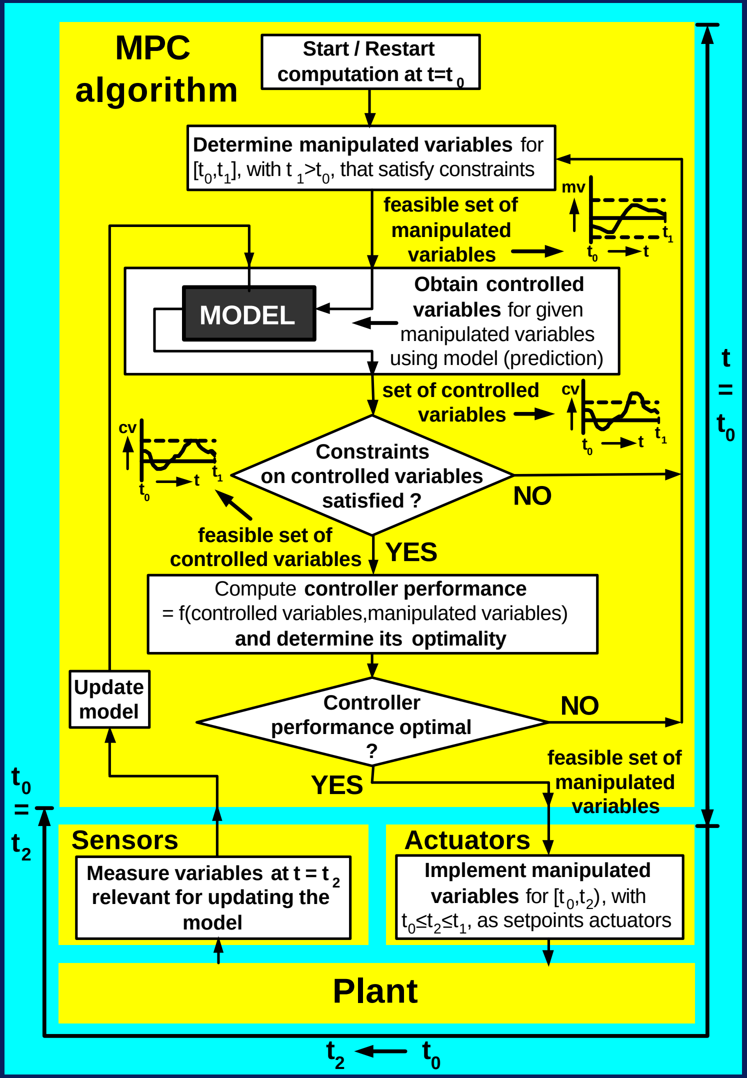
Inefficient control due to:

- Complex (multivariable) character of the process
- Presence of multiple conflicting control objectives
- Not being allowed to exceed certain constraints (limits)

Control of solid fuel combustion plants (2)

Model Predictive Control:
Computation of manipulated variables via solving on-line, at each sample instant, a mathematical optimization problem

Ingredients:
- Dynamic Model
- Objective function: reflects controller performance
- Constraints



MPC algorithm

Start / Restart computation at $t=t_0$

Determine manipulated variables for $[t_0,t_1]$, with $t_1>t_0$, that satisfy constraints

feasible set of manipulated variables

MODEL

Obtain controlled variables for given manipulated variables using model (prediction)

set of controlled variables

Constraints on controlled variables satisfied ?

NO

YES

feasible set of controlled variables

Compute **controller performance**
= f(controlled variables,manipulated variables)
and determine its optimality

Update model

Controller performance optimal ?

NO

YES

feasible set of manipulated variables

Sensors

Measure variables at $t = t_2$ relevant for updating the model

Actuators

Implement manipulated variables for $[t_0,t_2)$, with $t_0 \le t_2 \le t_1$, as setpoints actuators

Plant

OPTICOMB Project (1)

Optimization and design of biomass combustion systems

Objective:

Increasing flexibility of fuels and reducing emissions

Expected results:

- Reduction of emissions
- Innovative control concepts
- New grate system
- New furnace concept

OPTICOMB Project (2)

Sponsered by EU. Start January 2003. Duration 3.5 years

Coordination:	TNO
Partners:	University of Graz Eindhoven University Vyncke University of Lisbon National Swedish Research Institute Bio-energy plant Schijndel

Conclusions

A dynamical first principal model of grate firing systems is available

Validation has shown that the model is in good compliance with practical data

The model forms a good basis for improvement of combustion systems, in specific with respect to the control concept

Results have been demonstrated at biomass combustion systems

Development of MPC has been started