BEST
Bioenergy and Sustainable Technologies

Operational optimization and error detection in biomass boilers by model-based monitoring: methods and practice

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Christopher Zemann, Helmut Niederwieser, Markus Gölles

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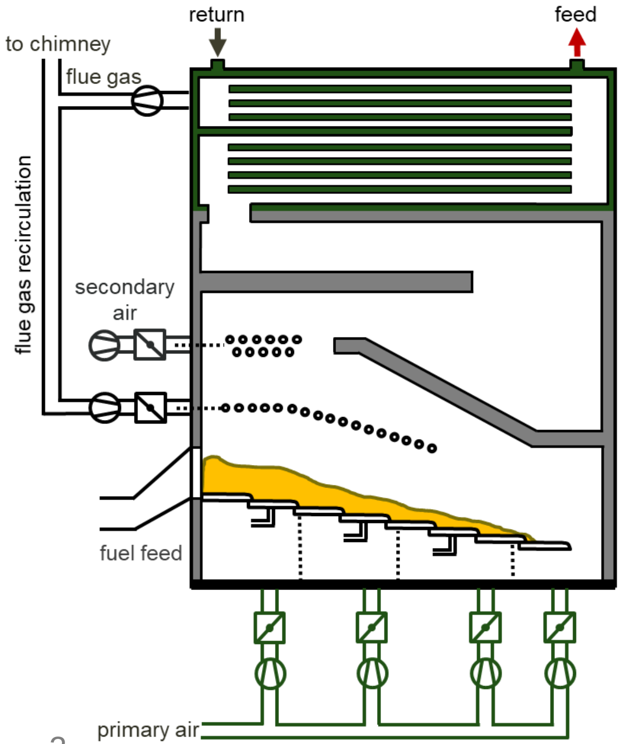
Continuous operational monitoring of medium- and large-scale biomass boilers



- **Purpose of continuous operational monitoring:**
  - detect errors and faults
  - identify possibilities for operational optimization

- **Problem in practice: high complexity and time consumption**
  - errors are frequently detected too late or not at all
    - inefficient operation → high operating costs
    - increased pollutant emissions → problems with regulators
    - costly secondary errors → to the point of complete plant failure
  - possibilities for optimization remain unused
    - also resulting in low efficiencies, high operating costs and unnecessary pollutant emissions.

Continuous operational monitoring of medium- and large-scale biomass boilers

- **Goal: develop computer algorithms that supports the plant operators in performing the complex task of continuous operational monitoring.**

- **Expected advantages:**
  - high degree of automation
    - quality of the monitoring stays the same (no tired or distracted operator)
    - reduce the workload of the operators and thus free up time for other tasks
  - possibility of simultaneous analysis of a large amount of information with a high level of detail
    - detect and even predict errors that operators did not see
      → correct errors before they lead to serious damage
    - identify changes in the operating conditions (e.g. fuel properties)
      → automated adaption to these changes in order to optimize operational behaviour

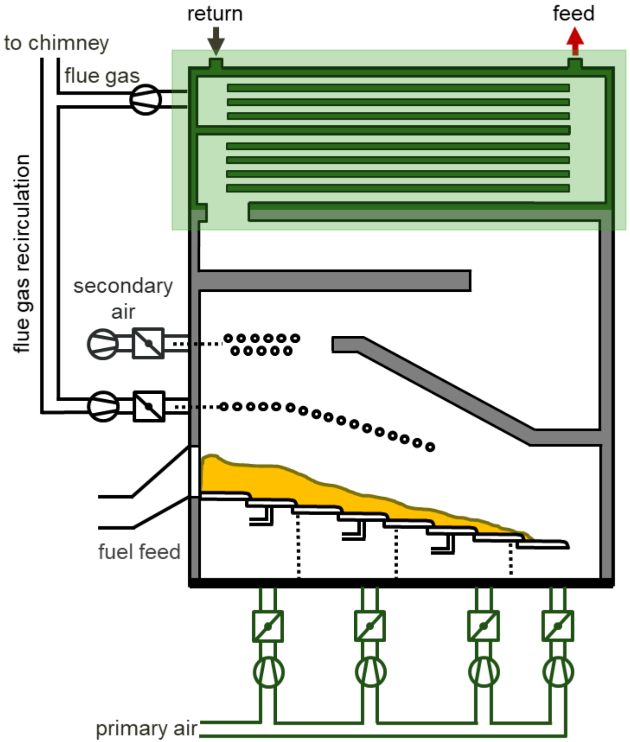
Example 1 - heat exchanger fouling

Problem description

- **Plants:**
  - biomass boilers with warm- or hot-water fire-tube heat exchanger
  - small-scale or medium-scale

- **Frequent error: heat exchanger fouling**
  - accumulation of deposits on heat transferring surfaces
  - if significant fouling remains undetected:
    - ➢ decreased efficiency
    - ➢ permanent damage to the heat exchanger

- **Problem: how to detect that significant fouling occurs?**
  - during revision: visual inspection
  - **during ongoing operation?**

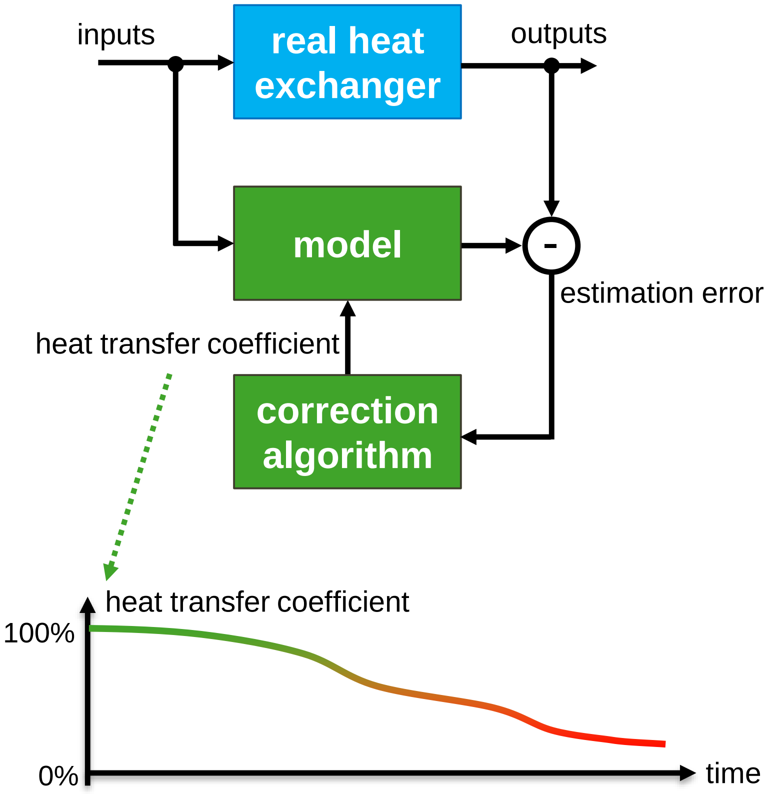


Example 1 - heat exchanger fouling
Methodology

- **Idea:** **develop an algorithm that automatically detects, whether the heat transfer coefficient deteriorates over time.**

- **Model-based monitoring:**
  - dynamic mathematical model of the heat exchanger
  - real time estimation of the model parameters using measurement data and an Extended Kalman Filter
  - one parameter is the heat transfer coefficient
  - ➢ “digital twin”
  - ➢ Plug&Play solution

- **Observe and analyze the rate of change of the estimated heat transfer coefficient**
  - change over time is a measure for the fouling rate

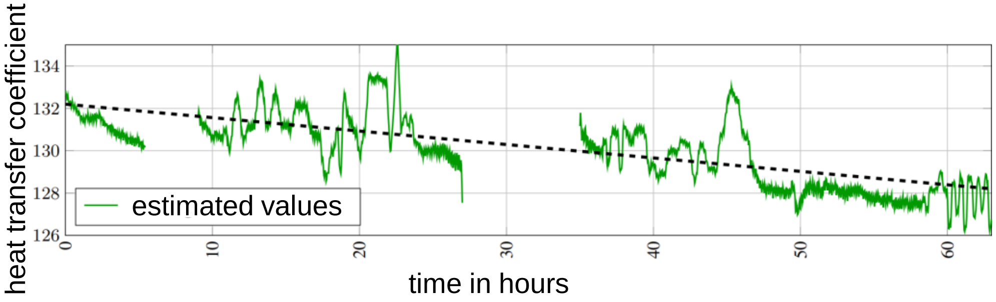


Example 1 - heat exchanger fouling

Exemplary results

- **Plant description:**
  - medium-scale fixed-bed biomass boiler
  - nominal capacity: 1 MW
  - fuel: wood chips
    (water content: ~30 w.t.%)

- **Measured data:**
  - water:
    - feed and return temperature
    - thermal output
  - flue gas:
    - residual oxygen content
    - temperature at the heat exchanger outlet
    - differential pressure over heat exchanger
- **Not measured:**
  - any mass flow except for the water mass flow



The heat transfer coefficient deteriorates by approximately 2.6% in only 60 hours.

Thus fouling occurs at a significant rate This would stay undetected.

Example 1 - heat exchanger fouling
Conclusion

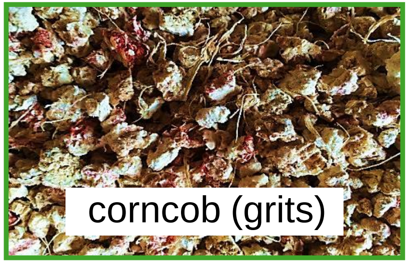
- **Method:**
  - provides a qualitative statement about the extent of fouling in heat exchangers
  - only standard measurement data is required
  - Plug&Play → no or only very simple parameterization necessary

- **Possible applications in practice:**
  - detect and counteract fouling before it becomes a problem → “predictive maintenance”
  - automatically adapt cleaning procedures on the fly
  - improve maintenance and service

Example 2 - fuel property estimation

Problem description

- **Plants:**
  - fixed-bed biomass boilers
  - small-scale or medium-scale
- **Challenge: constantly changing fuel properties**
  - adapt the boiler operation to changing fuel properties
    - ensure a complete combustion
    - maintain combustion temperature
    - ensure low pollutant emissions
    - avoid ash melting
- **Important fuel properties**
  - bulk density
  - water content
  - chemical composition (C, H, O)

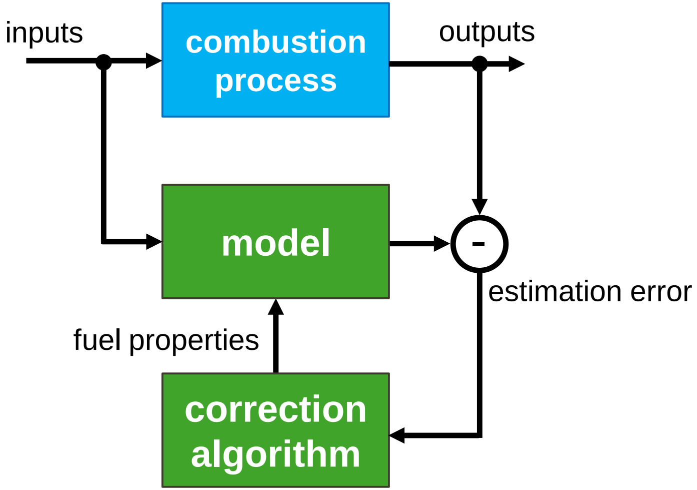


Example 2 - fuel property estimation
Methodology

- **Problem: how to identify the fuel properties?**
  - plant operators have an “idea” what fuel is currently being combusted
  - however, the exact fuel properties are not known and are constantly changing

- **Idea:** **develop an algorithm that estimates the fuel properties in real time**

- **Model-based monitoring:**
  - utilize a dynamic mathematical model of the fuel feed and the fuel feed as well as mass- and substance balance equations
  - real time estimation of the model parameters using measurement data and an Extended Kalman Filter
  - some of the parameters represent fuel properties
  - “digital twin”

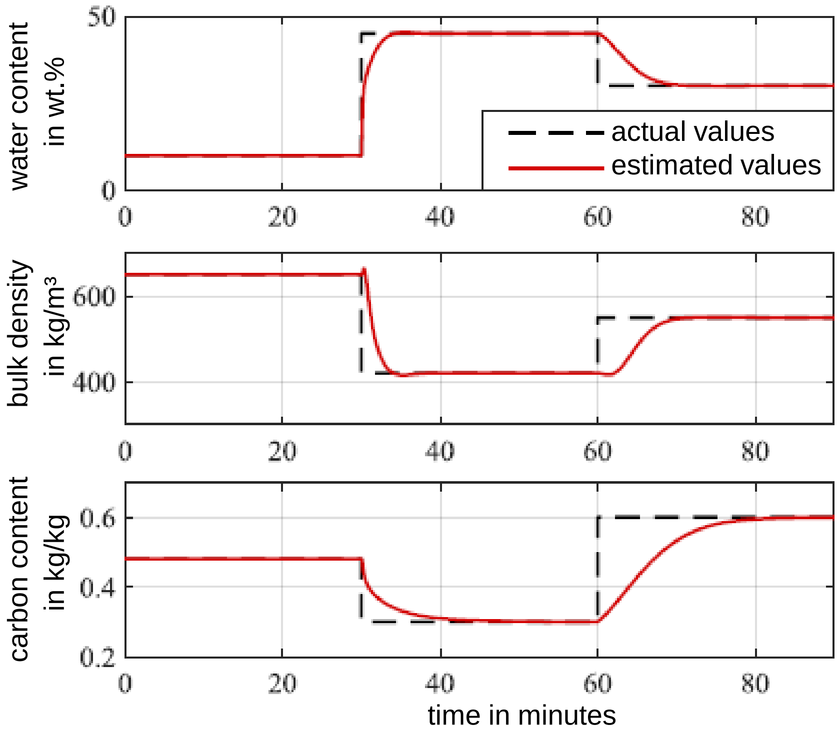


Example 2 - fuel property estimation

Exemplary results - simulations

- **Plant description:**
  - small-scale fixed-bed biomass boiler
  - nominal capacity: 50 kW
  - fuel properties: changing over time

- **Measured data:**
  - flue gas:
    - residual oxygen content
    - water content
  - mass flows:
    - primary air
    - secondary air
    - flue gas



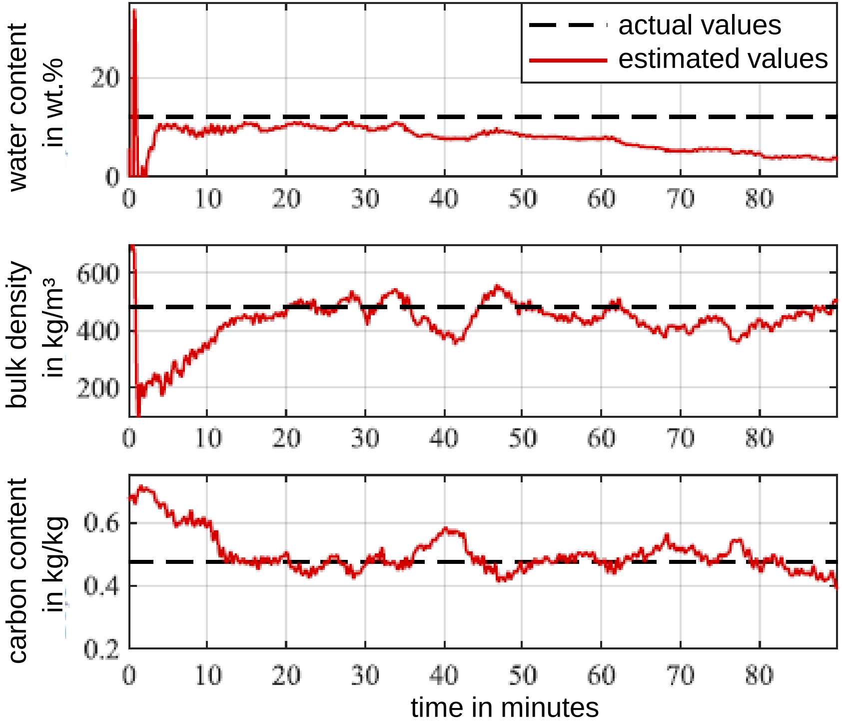
Fuel properties can be accurately identified.

Example 2 - fuel property estimation

Exemplary results - measured data

- **Plant description:**
  - small-scale fixed-bed biomass boiler
  - nominal capacity: 50 kW
  - fuel properties: corncob grits

- **Measured data:**
  - flue gas:
    - residual oxygen content
    - water content
  - mass flows:
    - primary air
    - secondary air
    - flue gas



Fuel properties can be accurately identified. Measurement errors introduce estimation errors.

Example 2 - fuel property estimation
Conclusion

- **Method:**
  - provides accurate estimates of the most relevant fuel properties
  - requires additional measurement data
  - must be parameterized

- **Possible applications in practice:**
  - adapt the control strategy (primary air ratio) and grate movement to
    - improve combustion quality
    - reduce pollutant emissions
    - avoid ash melting problems
  - warn users, if fuel properties are too different from the intended fuel

Outlook and other applications of model-based monitoring

- **Supports the plant operators in the most difficult tasks**
  - more accurate error detection
  - generally more optimally operated plants
    - higher efficiencies
    - lower pollutant emissions
  - lower work load for plant operators

- **Other applications**
  - biomass combustion
    - e.g. predictive maintenance to predict pump or fan failure
  - biomass gasification
    - e.g. determine internal state of the gasifier → improve operational stability and fuel flexibility
  - heating grids
    - e.g. heat loss detection and localization
  - any technical process

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