Modern control strategies for biomass combustion systems in residential heating systems

6th Central European Biomass Conference
IEA-Workshop: TASK 32

Markus Gölles, Christopher Zemann

Graz, 23.01.2020
<table>
<thead>
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<th>control of the combustion process</th>
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<td>interaction with the heating system</td>
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Control strategies for wood stoves

Control of the combustion process

- utilization of finite-state machines

Interaction with the heating system

- very rare
- rule-based strategies
- manufacturer-specific
Control strategies for firewood boilers

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**control of the combustion process**

**interaction with the heating system**
Combustion control for firewood boilers – overview

**Goal:** control strategy which simultaneously guarantees good combustion conditions and ensures that the water temperature is kept at the desired value.

**controlled variables**
- feed temperature
- residual oxygen content of the flue gas

**manipulated variables**
- suction fan frequency
- primary air control valve
- secondary air control valve
- boiler pump frequency
Combustion control for firewood boilers – concept

decoupling
utilization of the mass flow of water to decouple the feed temperature from the combustion process

targeted combustion control
utilization of the mass flow controllers to ensure good combustion conditions
Combustion control for firewood boilers – results

The application of the new combustion control leads to:
- faster start-up
- reduced fluctuations in the residual oxygen content of the flue gas
- reduced pollutant emissions

The application of the new combustion control leads to:
- reduced settling time
- reduced overshoot
- reduced fluctuations
Control strategies for firewood boilers

- **manually fed**
  - stoves
  - firewood boilers
- **automatically fed**
  - pellets boilers
  - wood chip boilers

**control of the combustion process**

**interaction with the heating system**
Energy management system for firewood boilers

**Operation of manually fed boilers**
- batch combustion → supply of heat depends on ignition time
- consideration refill windows defined by the user → user comfort

- utilization of forecasting methods using weather forecasts
- self-learning to adapt to the user behavior
Exemplary results from the application of an energy management system for firewood boilers

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<th>Conventional operation</th>
<th>Superordinate control</th>
<th>± %</th>
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<tr>
<td>energy delivered to consumers</td>
<td>783 kWh</td>
<td>782 kWh</td>
<td>± 0 %</td>
</tr>
<tr>
<td>number of refills (total / within refill windows)</td>
<td>5 / 4</td>
<td>6 / 6</td>
<td>+1 / +2</td>
</tr>
<tr>
<td>utilized solar yield</td>
<td>117 kWh</td>
<td>126 kWh</td>
<td>+ 8 %</td>
</tr>
<tr>
<td>storage losses</td>
<td>122 kWh</td>
<td>105 kWh</td>
<td>- 14 %</td>
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→ improved efficiency

→ improved user comfort due to no refills outside of defined refill windows
Control strategies for automatically fed boilers

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- **Control strategies for automatically fed boilers**
  - control of the combustion process
  - interaction with the heating system
Combustion control for wood chip boilers - overview

**Goal:** control strategy which simultaneously guarantees good combustion conditions and ensures that the water temperature is kept at the desired value.

**controlled variables**
- feed temperature
- residual oxygen content of the flue gas
- primary air ratio

**manipulated variables**
- fuel feed
- primary air fan
- secondary air fan
- boiler circuit pump
Combustion control for wood chip boilers - concept

decoupling utilization of the mass flow of water to decouple the feed temperature from the combustion process

targeted combustion control utilization of the mass flow controllers to ensure good combustion conditions
Combustion control for wood chip boilers – results (1)

The application of the new combustion control:
- leads to reduced fluctuations in the feed temperature
Combustion control for wood chip boilers – results (2)

The application of the new combustion control:
- leads to reduced fluctuations in the residual oxygen content of the flue gas
- enables the targeted control of the primary air ratio
Control strategies for automatically fed boilers

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- Control strategies for automatically fed boilers
- manually fed
  - stoves
  - firewood boilers
- automatically fed
  - pellets boilers
  - wood chip boilers

- control of the combustion process
- interaction with the heating system

...
Definition of a desired thermal output of the boiler depending on the state of the buffer storage.

- **ignition**
  - start combustion process if $S_1 < T_1$
  - start combustion process if ignition request from user

- **standard operation**
  - if $S_3 < T_2$, increase thermal output
  - else: decrease thermal output
  - if $S_1 < T_1$, maximum thermal output

- **shut-down**
  - if $S_5 > T_3$, shut-down boiler
Only desired values for the first 15 minutes are transmitted.

After 15 minutes the optimization is repeated with new measured variables.
Simple forecasting methods

Forecasting method for the load demand in residential heating systems:
- simple to implement
- self-learning (based on measurement data from weather forecasts)
  ➢ no parametrization required

![Graph showing load demand and temperature comparison]
The system is modular: it allows a quick configuration from standard components. Variable prices and availability of systems can be taken into account.
## Conclusion

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- **control of the combustion process**
- **interaction with the heating system**
- **additional topics**
Knowledge about the mass flow of flue gas can be used in control strategies to ensure good combustion conditions. → difficult to measure in biomass boilers

Estimation of fuel properties such as the carbon content (\(w_C\)) and lower heating value (LHV) during the operation of the biomass boiler.
A long-term validation has been carried out at a biomass boiler in a district heating plant (nominal capacity of 2.5 MW\textsubscript{th}) → Nov. 2017 to Mar. 2019 (5 months)

During the long-term validation the modular CO-\(\lambda\)-optimization reduced the
- fuel consumption by -3.8%
- CO-emissions by -200 mg/m\(^3\)
- total dust emissions by -19.5%
## Conclusion

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- Control of the combustion process
- Interaction with the heating system
- Estimation of non-measurable quantities and CO-$\lambda$-optimization
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