Model-based estimation of the flue gas mass flow in biomass furnaces

6. Central European Biomass Conference
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Helmut Niederwieser - Area Automation and Control

Motivation

Flue gas mass flow:

- Highly informative value about quality of combustion process
- Possible applications:
  - Utilization in control strategies
  - Monitoring of combustion process


1

Measurement of flue gas mass flow:

- Impractically large inflow and outflow zones
- High costs
- Sensor fouling


2

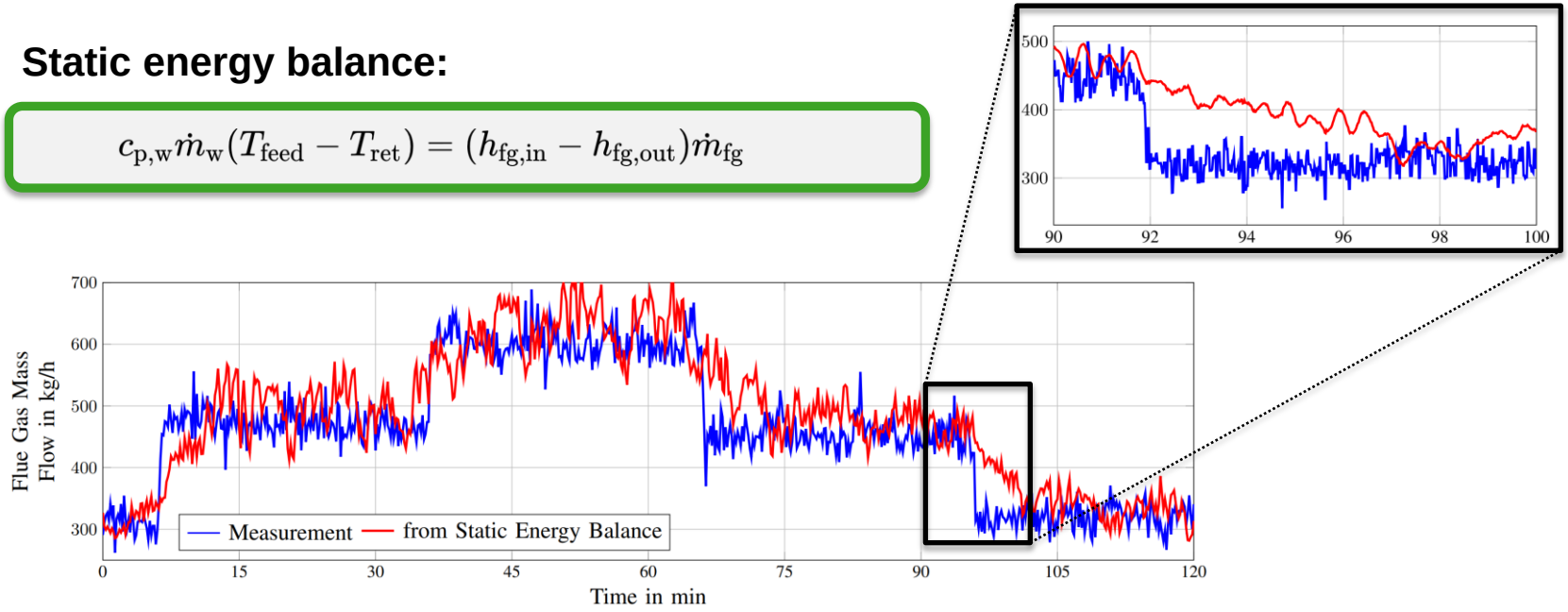
→ **model-based estimation algorithm**

[1] https://www.chemicalprocessing.com/articles/2007/214/
[2] https://www.hrs-heatexchangers.com/news/understanding-and-preventing-heat-exchanger-fouling/

Calculation of the flue gas mass flow from static energy balance of heat exchanger

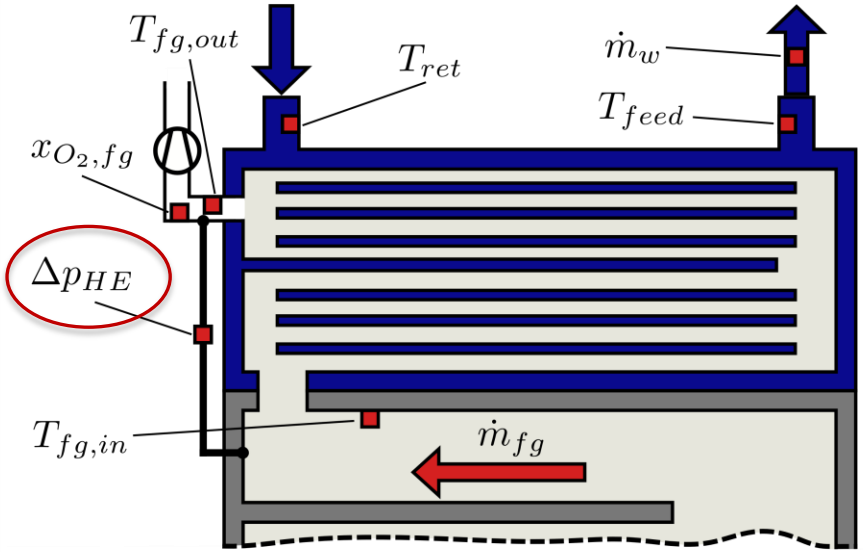
Static energy balance:

$$c_{\mathrm{p,w}} \dot{m}_{\mathrm{w}} (T_{\mathrm{feed}} - T_{\mathrm{ret}}) = (h_{\mathrm{fg,in}} - h_{\mathrm{fg,out}}) \dot{m}_{\mathrm{fg}}$$



→ **high variance** and **bad dynamic response**

Typically available measurements



$T_{\mathrm{fg,in}}$... flue gas inlet temperature
Δp_{HE}...differential pressure
$x_{O_2,\mathrm{fg}}$... oxygen content of the flue gas
$T_{\mathrm{fg,out}}$...flue gas outlet temperature
T_{ret}... return temperature
$\dot{m}_{\mathrm{w}}$... water mass flow
T_{feed}... feed temperature
$\dot{m}_{\mathrm{fg}}$... flue gas mass flow

→ utilization of **fast differential pressure measurement**

Modeling of gas tube heat exchangers

- **Static differential pressure model:**

$$\dot{m}_{fg} = \sqrt{\frac{\Delta p_{HE}}{R}} \quad \text{with} \quad R \ldots \text{mass flow resistance}$$

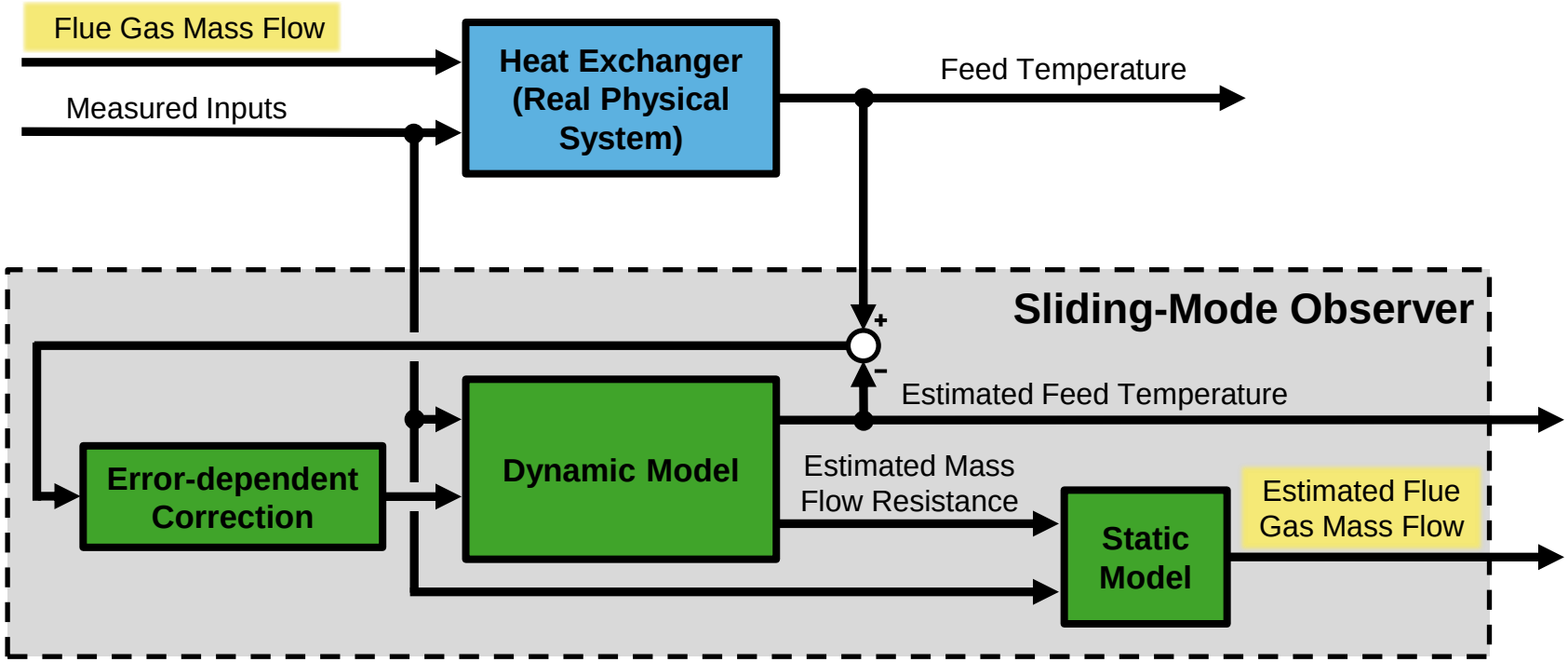
$\rightarrow R$ changes over time with different operation points and fouling

- **Dynamic energy balance of heat exchanger**

$$\frac{\mathrm{d}T_{\mathrm{feed}}}{\mathrm{d}t} = \frac{\dot{m}_{\mathrm{w}}}{c_\tau}(T_{\mathrm{ret}} - T_{\mathrm{feed}}) + \frac{h_{\mathrm{fg,in}} - h_{\mathrm{fg,out}}}{c_\tau c_{\mathrm{p,w}}}\dot{m}_{\mathrm{fg}}$$

1. **Combination of both models** is used to track R
2. **Static differential pressure model** is used to calculate $\dot{m}_{\mathrm{fg}}$

Design of Sliding-Mode observer



Experimental validation

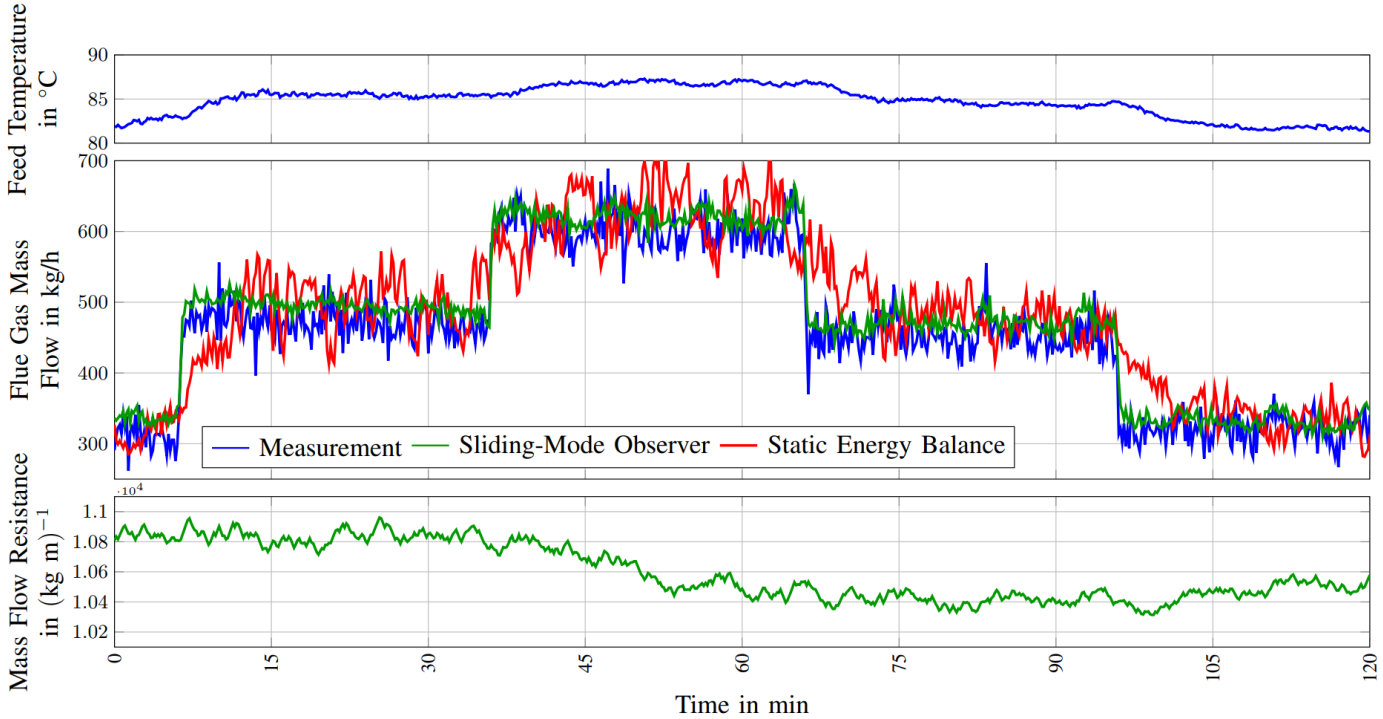
- **Medium-scale biomass grate boiler**
  - warm water fire-tube boiler:
    - nominal capacity 180 kW
    - no automated cleaning
  - fuel:
    - typical wood chips (G30)
    - average water content: 30 wt% w.b.

- **Experimental procedure**
  - manual cleaning of the heat exchanger before test runs
  - step-wise variations of the flue gas mass flow
  - variations of the feed temperature

- **Reference measurement**
  - Prandtl-type Pitot tube (manually cleaned every 12 hours)

Exemplary results 1

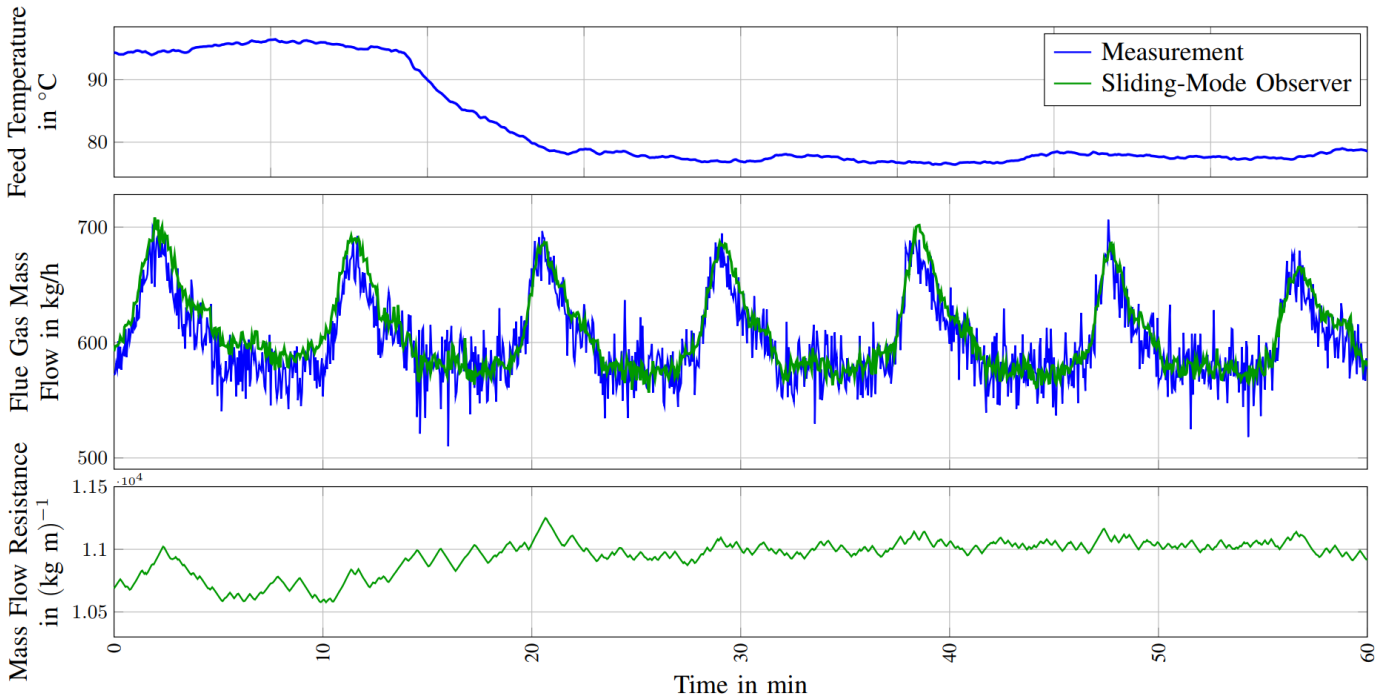
Large variations in the flue gas mass flow



→ **highly satisfying dynamic response**

Exemplary results 2

Steep change of the feed temperature



→ **high accuracy** even during **steep change of feed temperature**

Conclusion

- New approach for **online determination of the flue gas mass flow** in biomass furnaces:
  - high accuracy
  - satisfying dynamic response
  - robust against fouling of plant components

- **Possible applications:**
  - use in control strategies
  - online monitoring of combustion process

Niederwieser, H., Zemann, C., Goelles, M. & Reichhartinger, M. (2019). Model-based Estimation of the Flue Gas Mass Flow in Biomass Boilers. (submitted to IEEE Transactions on Control Systems Technologies).

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