

Model-based Control of an Additively Manufactured Reactor for Catalytic Methanation of Biogenic Syngas



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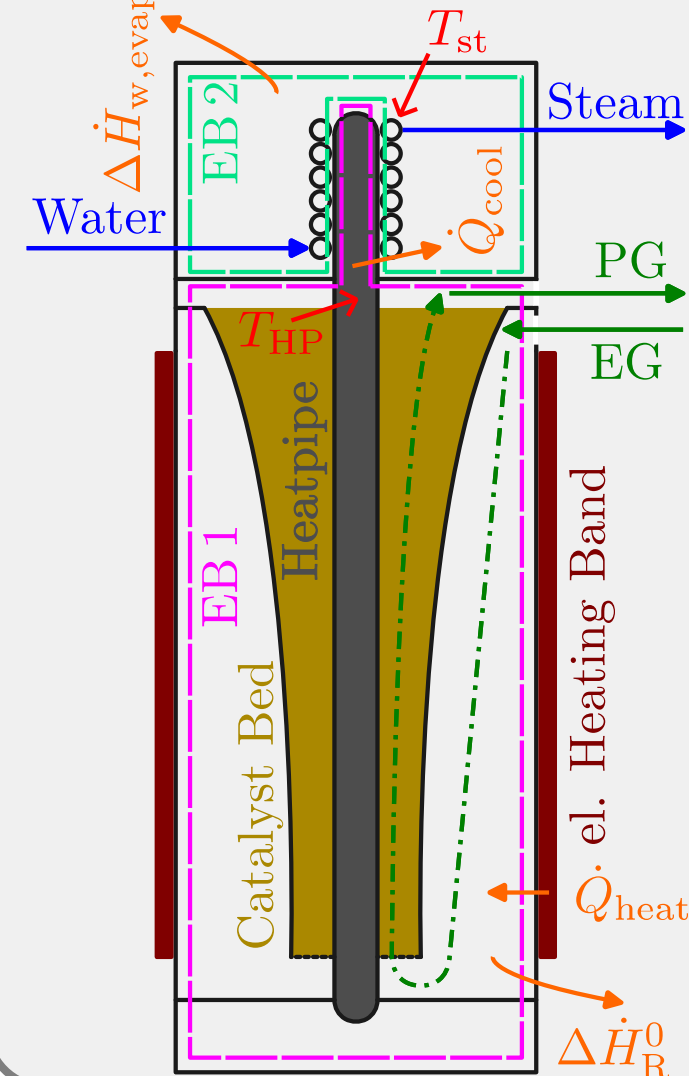
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Introduction and Motivation

Methanation of a product gas from biomass gasification is a promising way to generate green synthetic natural gas (SNG) to substitute fossil-based energy carriers.

Currently, the production costs for green SNG are not competitive, which is the technology's main drawback. A suitable control concept of the methanation reactor leading to an increased degree of plant automation and efficiency can contribute towards lowering the production cost of green SNG, with the goal of competitive prices in an industrial setting.

Process Description



- Educt gas (EG) is converted into product gas (PG), releasing energy
- Heatpipe (HP) transports energy out of catalyst bed
- Heatpipe is cooled with water, generating steam

Modelling

Static energy balance over EB2

$$0 = \dot{H}_w - \dot{H}_{st} + \dot{Q}_{cool} - \Delta \dot{H}_{w, \text{evap}} \\ \Leftrightarrow T_{st, f} = f(\dot{m}_w, T_{HP})$$

Dynamic energy balance over EB1 with Hammerstein model extension for EB2

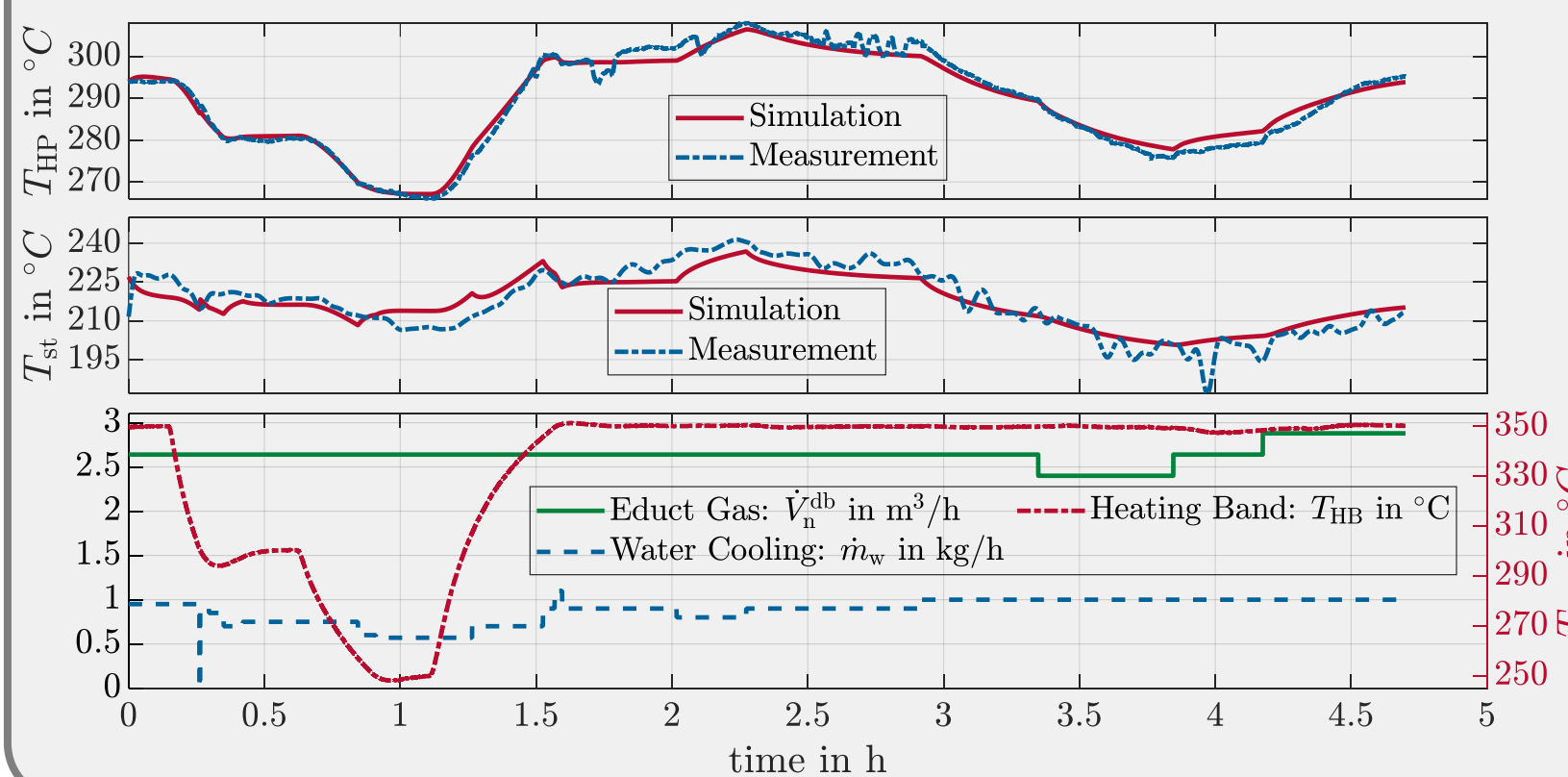
$$\frac{d}{dt} \begin{bmatrix} T_{HP} \\ T_{st} \end{bmatrix} = \begin{bmatrix} \frac{1}{\tau_{HP}} \left(\dot{H}_{EG}^{wb} - \dot{H}_{PG}^{wb} - \Delta \dot{H}_R^0 + \dot{Q}_{heat} - \dot{Q}_{cool} \right) \\ \frac{1}{\tau_w} (-T_{st} + T_{st, f}) \end{bmatrix}$$

$$p_{HP} = f(T_{HP})$$

Convective heat transfers

$$\dot{Q}_{heat} = \alpha_{heat} (T_{HB} - c_{heat} T_{HP}) \\ \dot{Q}_{cool} = \underbrace{(\alpha_{cool,1} \dot{m}_w^{0.8} + \alpha_{cool,2})}_{\bar{\alpha}_{cool}} (T_{HP} - T_{st})$$

Model validation after optimization-based parameter identification

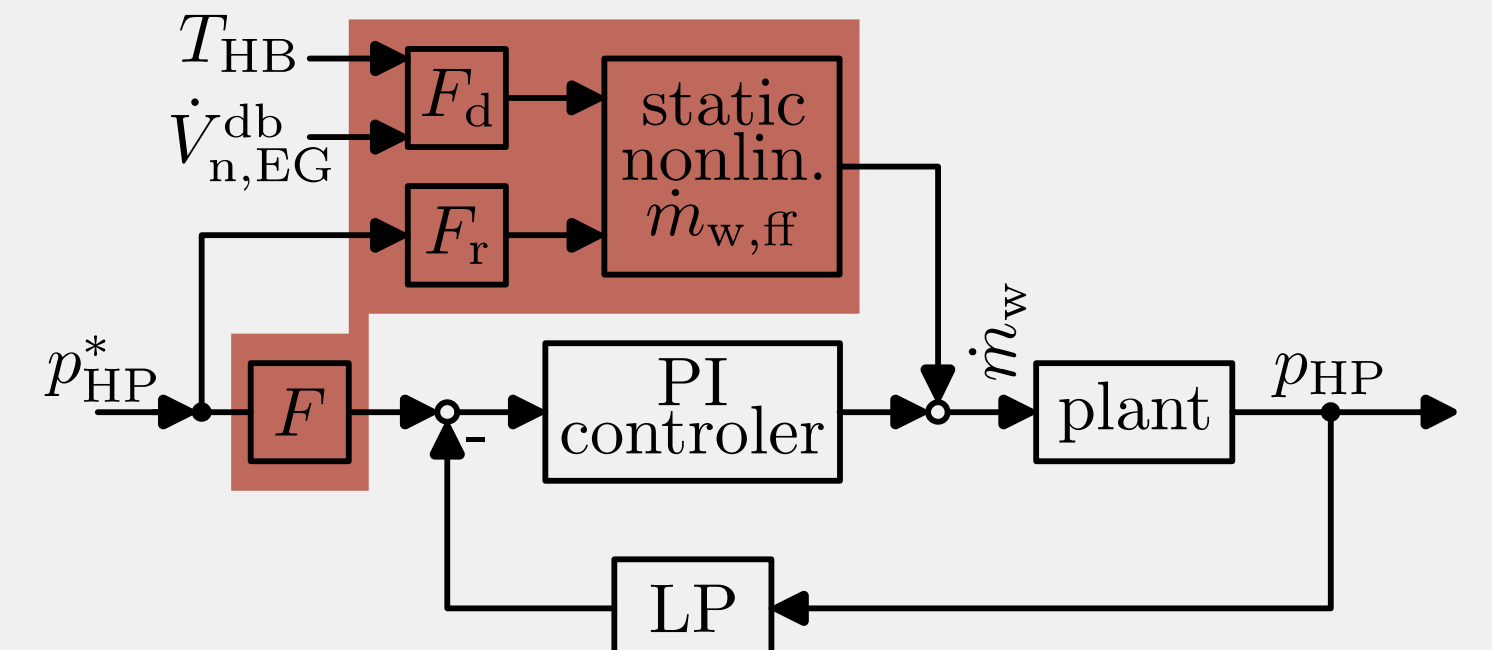


Controller Design

By varying the cooling water mass flow ($\dot{m}_w$) to control the heat pipe pressure (y), the temperature of the catalyst bed can be influenced.

Goal of control concepts: Disturbance rejection

- 1st control concept: PI controller + reference shaping
- 2nd control concept: PI controller with dynamic model-based feed forward control

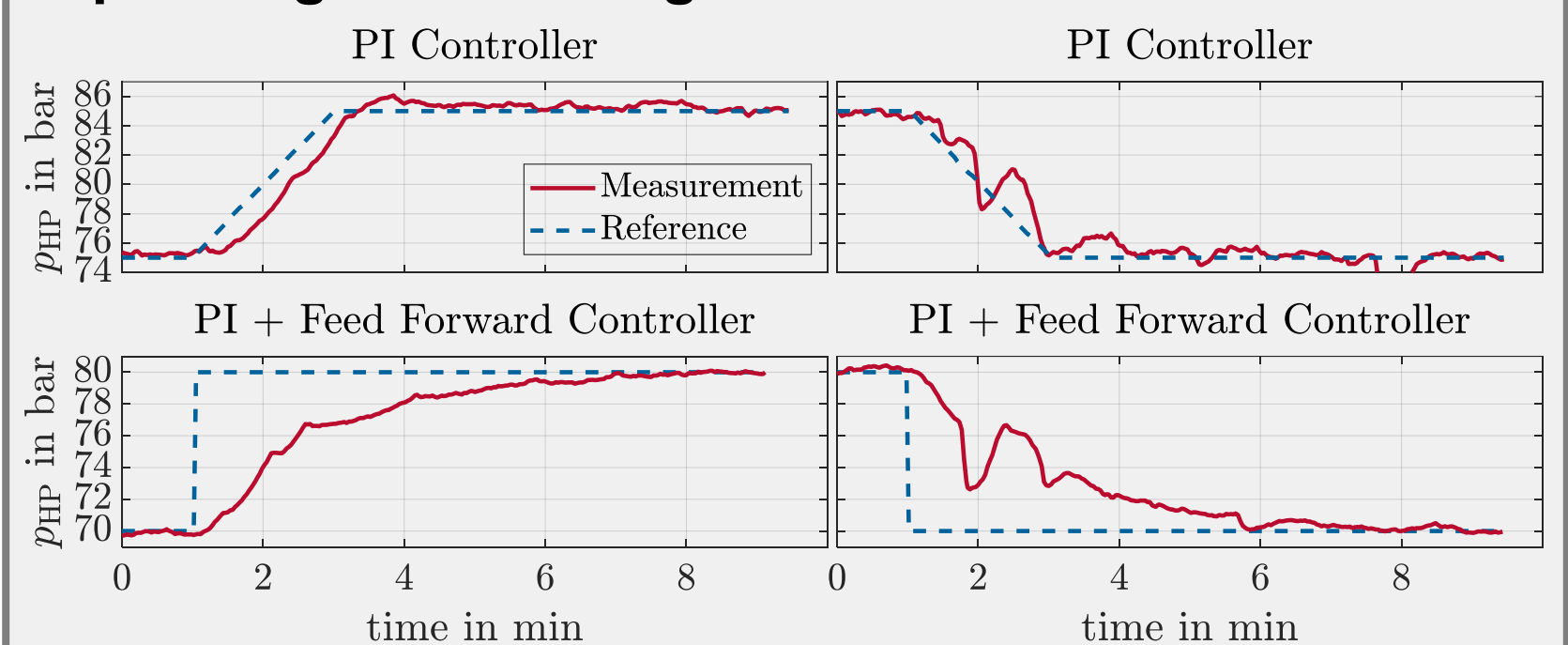


$$\dot{m}_{w,ff} = \frac{\dot{H}_{EG}^{wb} - \dot{H}_{PG}^{wb} - \Delta \dot{H}_R^0 + \dot{Q}_{heat}}{\text{den}}$$

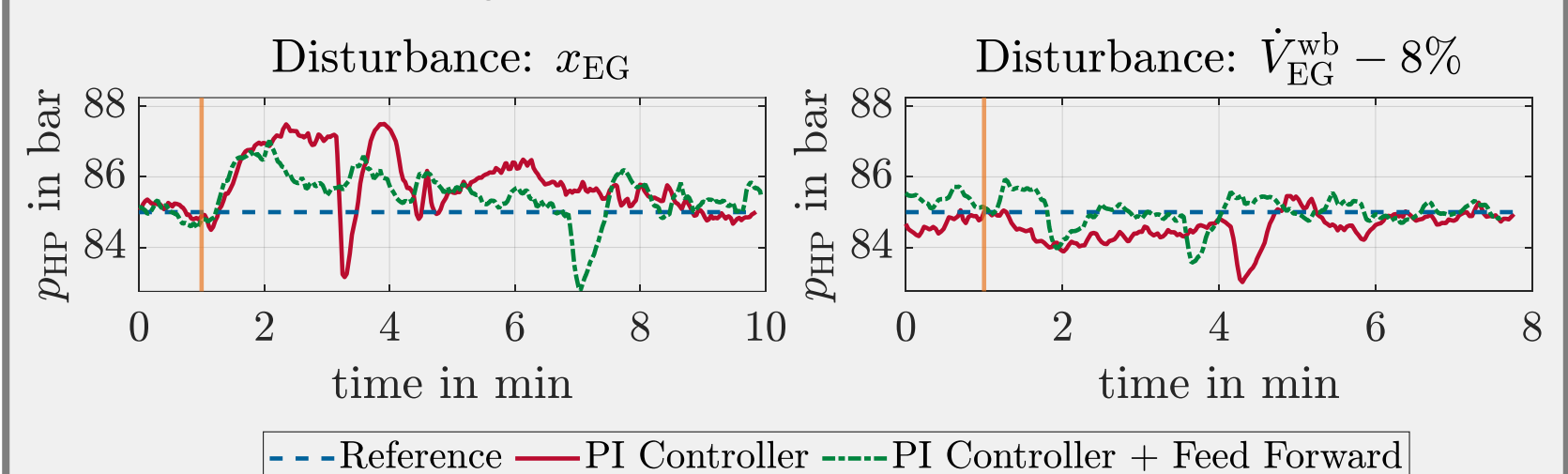
$$\text{den} = +\Delta h_{w, \text{evap}} + \frac{d_{st,m}}{M_w} - c_{p,w} (T_w - T_{ref}) \\ \frac{k_{st,m}}{M_w} \left[T_{HP} - \frac{1}{\tilde{\alpha}_{cool}} \left(\dot{H}_{EG}^{wb} - \dot{H}_{PG}^{wb} - \Delta \dot{H}_R^0 + \dot{Q}_{heat} \right) \right]$$

Practical Validation

Operating Point Changes



Disturbance Rejection



Conclusions and Outlook

- Two control concepts with a satisfactory disturbance rejection have been designed
- Optimization of the methane yield via a targeted variation of reaction conditions
- Application of the control concepts in the full process chain compared to lab experiments
- Design of advanced control concepts such as e.g. Model Predictive Control (MPC)

AREA 2.2 Automation and Control

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