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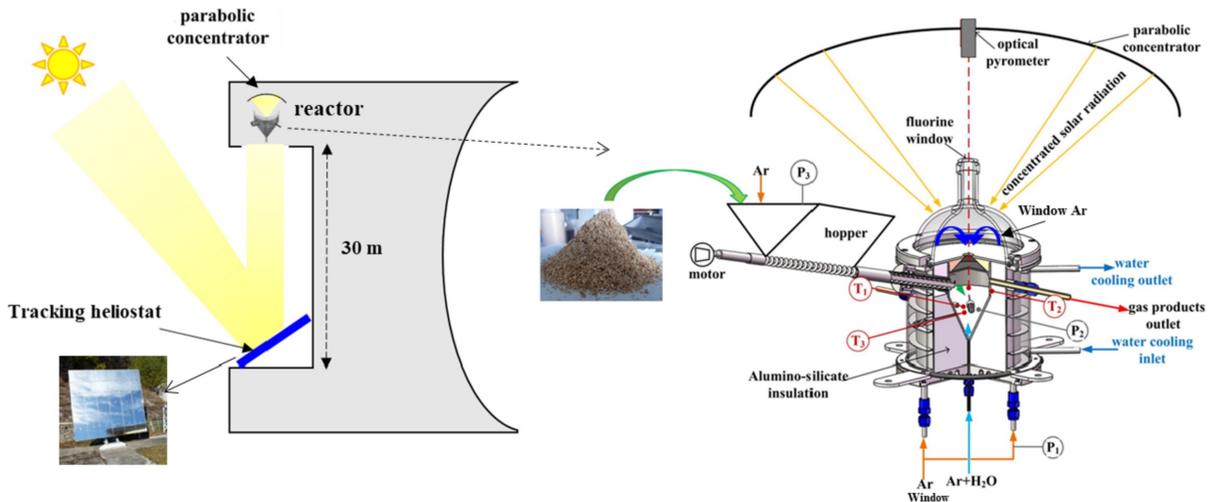
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Model-based predictive control of a solar reactor dedicated to syngas production

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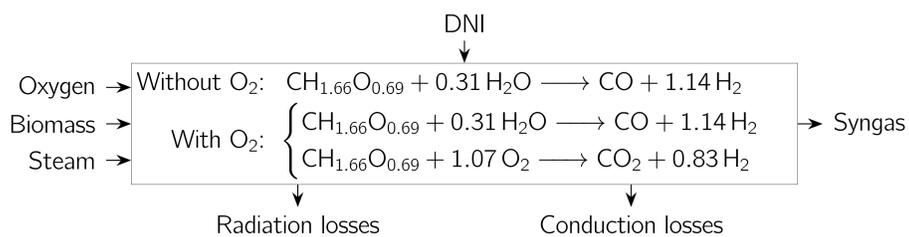
Solar reactor for syngas production

- ▶ A solar spouted-bed gasifier has been conceived by Bellouard et al. [1], and its hybrid solar-autothermal operation has been investigated by Boujjat et al. [2] and Curcio et al. [3].
- ▶ This work aims at conciliating the solar-autothermal hybrid control strategy of a gasifier with the efficient implementation of a model-based predictive control (MPC) algorithm.
- ▶ Goal: maintain reactor's temperature to ensure its stability and optimal chemical reactions.



- [1] Q. Bellouard et al. "Biomass Gasification in an Innovative Spouted-Bed Solar Reactor: Experimental Proof of Concept and Parametric Study". In: Energy Fuels 31.10 (Sept. 2017).
- [2] H. Boujjat et al. "Experimental and numerical study of a directly irradiated hybrid solar/combustion spouted bed reactor for continuous steam gasification of biomass". In: Energy 189 (Dec. 2019).
- [3] A. Curcio et al. "Experimental assessment of woody biomass gasification in a hybridized solar powered reactor featuring direct and indirect heating modes". In: International Journal of Hydrogen Energy 46.75 (Oct. 2021).

Solar reactor modeling

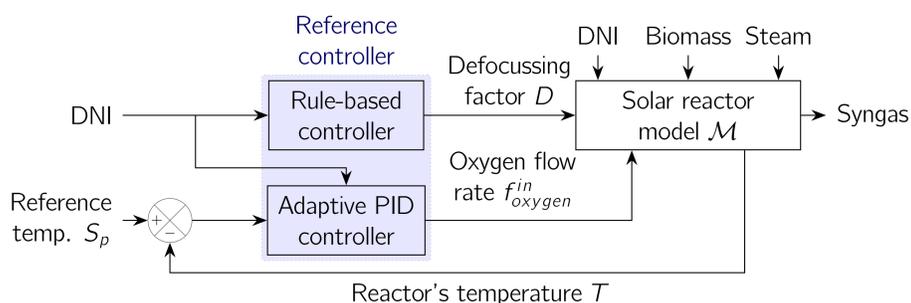


The model also includes the thermal balance of the reactor walls, and a thermodynamic calculation using the open-source library Cantera [4].

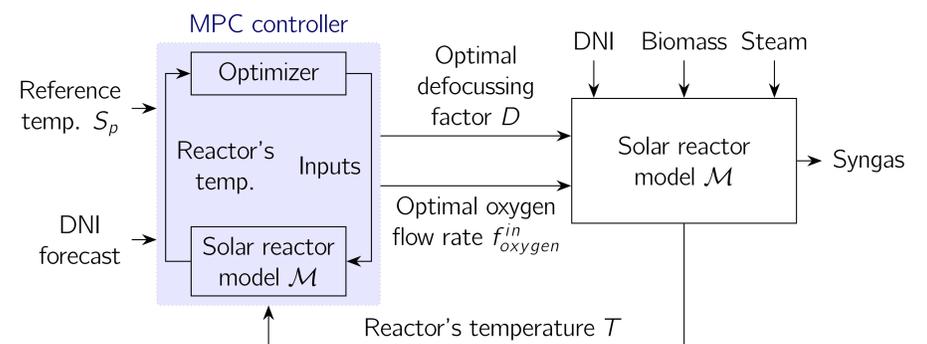
[4] D. G. Goodwin et al. "Cantera: An object-oriented software toolkit for chemical kinetics, thermodynamics, and transport processes". <https://www.cantera.org> (2022).

Reference controller

- ▶ Oxygen flow rate is controlled by an adaptive proportional integral derivative (PID) controller with optimized gains.
 - ▶ Defocussing factor is controlled by a rule-based controller as follows:
- $$D(t) = \begin{cases} 1, & \text{if DNI}(t) \leq 800 \text{ W m}^{-2} \text{ and } T(t) < 1473 \text{ K} \\ \frac{800}{\text{DNI}(t)}, & \text{if DNI}(t) > 800 \text{ W m}^{-2} \text{ and } T(t) > 1473 \text{ K} \end{cases}$$



Model-based predictive controller



- ▶ MPC strategy 1: maintain the reactor's temperature at any cost.

$$\begin{aligned} & \text{minimize}_{D, f_{oxygen}^{in}} \sum_{k=1}^n (T(t+k) - S_p)^2 \\ & \text{where } T(t+1) = \mathcal{M}(D(t), f_{oxygen}^{in}(t), T(t)) \\ & \text{subject to } 0 \leq D(t+k) \leq 1 \text{ and } 0 \leq f_{oxygen}^{in}(t+k) \leq 2 \end{aligned}$$

- ▶ MPC strategy 2: maintain the reactor's temperature, while minimizing O₂ consumption and maximizing solar energy use.

$$\begin{aligned} & \text{minimize}_{D, f_{oxygen}^{in}} \sum_{k=1}^n (\alpha(T(t+k) - S_p)^2 + \beta f_{oxygen}^{in}(t+k)^2 - \gamma D(t+k)^2) \\ & \text{where } T(t+1) = \mathcal{M}(T(t), D(t), f_{oxygen}^{in}(t)) \\ & \text{subject to } 0 \leq D(t+k) \leq 1 \text{ and } 0 \leq f_{oxygen}^{in}(t+k) \leq 2 \end{aligned}$$

- ▶ DNI forecasts: perfect forecasts, smart persistence forecasts, and proposed image-based forecasts.

Simulation results over one week and case studies

| Strategies | Performance metrics | Perfect forecasts | Image-based forecasts | Smart persistence forecasts |
|--------------------|---------------------------|-------------------|-----------------------|-----------------------------|
| MPC strategy 1 | RMSE [K] | ≪0.01 | 1.34 | 1.45 |
| | O ₂ cons. [kg] | 41 920.00 | 36 365.80 | 38 509.00 |
| | ATV [K] | ≪0.01 | 1.32 | 1.32 |
| MPC strategy 2 | RMSE [K] | 0.07 | 1.60 | 1.71 |
| | O ₂ cons. [kg] | 31 968.33 | 32 091.00 | 32 089.23 |
| | ATV [K] | 0.03 | 1.54 | 1.54 |
| Reference strategy | RMSE [K] | | 4.88 | |
| | O ₂ cons. [kg] | | 31 933.00 | |
| | ATV [K] | | 2.27 | |

- ▶ Performance metrics: root mean squared error (RMSE), O₂ consumption, and average temperature variation (ATV).
- ▶ The MPC controller, with all forecast models, outperforms the reference controller at the cost of an O₂ consumption increase.
- ▶ Integration of image-based forecasts results in better performance for both strategies.
- ▶ MPC strategy 1 is recommended if low RMSE and ATV values are required, while MPC strategy 2 is preferable if O₂ consumption should be minimized.

