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Development of an Indirectly Heated Solar Reforming Process

Fig. 1: Solar tower Jülich in operation

Introduction & Aim

- Chemical storage of solar energy by reforming of methane:

$$CH_4 + H_2O + 206\frac{kJ}{mol} \rightleftharpoons 3H_2 + CO$$

- Indirectly heated solar reforming:
  - Open volumetric solar receiver converts radiation into heat
  - Heat transfer fluid (air) heats reforming reactor
  - **Overall process efficiency unknown**

Open Volumetric Receiver Modelling

- One channel model of honeycomb absorber structure, acc. to Pitz-Paal (1993)
- Air return ratio (ARR): Fraction of air re-sucked into absorber, as varied parameter
  - Reference: 0.6

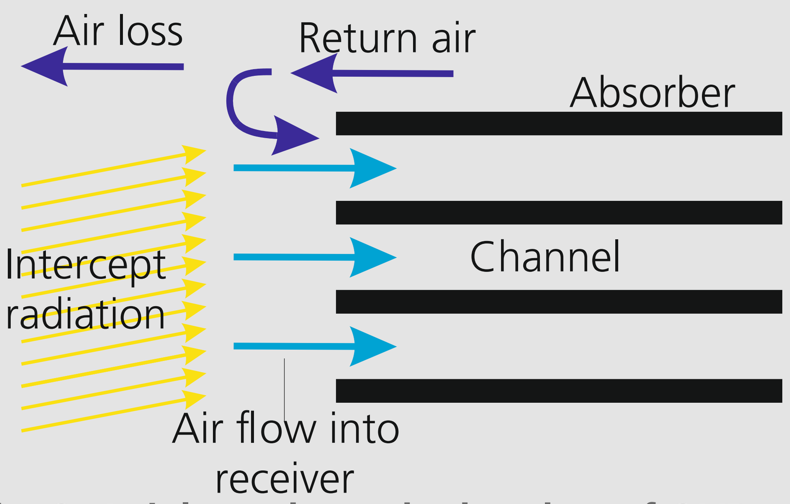

Fig. 2: Axial cut through absorber of OVR

Reference Process

- 50 MW intercept radiation as reference
- 56 - 65% of absorbed energy is available as off-heat
- T_{air} after feed-water evaporation > 350°C; additional cooling possible

→ Utilization of excess heat for electricity generation in water-steam-cycle.

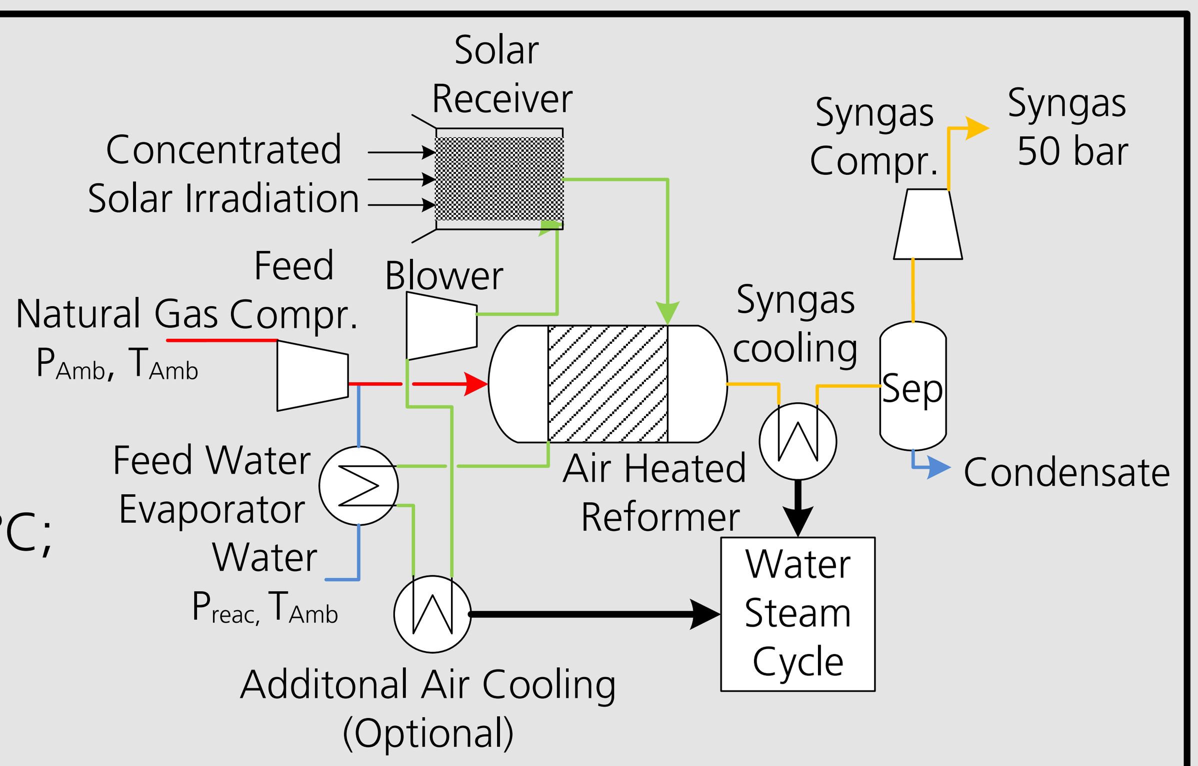

Fig. 5: Simplified flowsheet of the indirectly heated solar reforming process

Air Heated Reformer Modelling

- Bundle of identical jacketed tubes, reaction in inner tube, annulus for heat transfer
- Pseudo homogeneous 1-D steady state model, kinetics by Xu and Froment (1989)

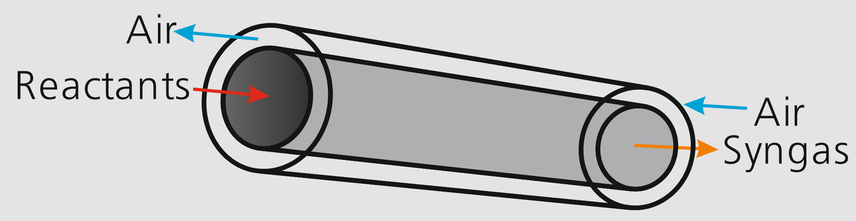

Fig. 3: Jacketed tube of air heated reformer

- Validated with data by Wesenberg (2006) (cf. fig.3): Good agreement

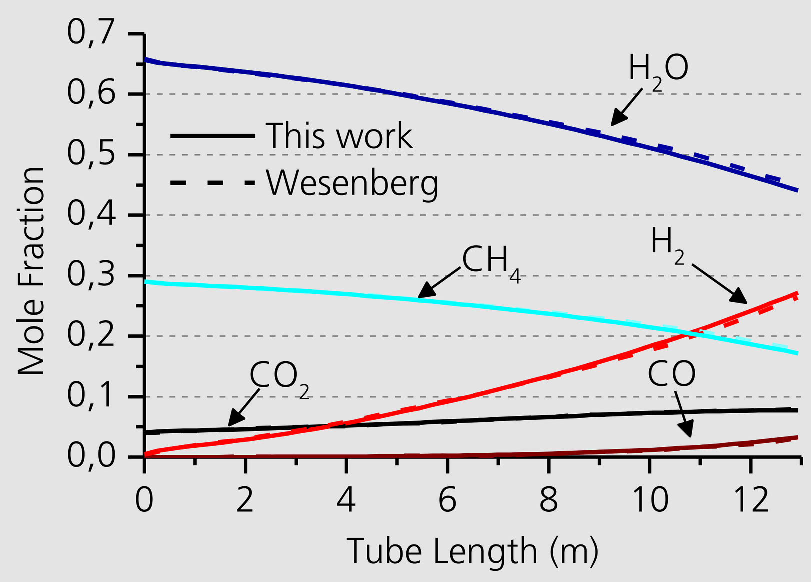

Fig. 4: Mole fraction over reactor length in both models

Process Efficiency

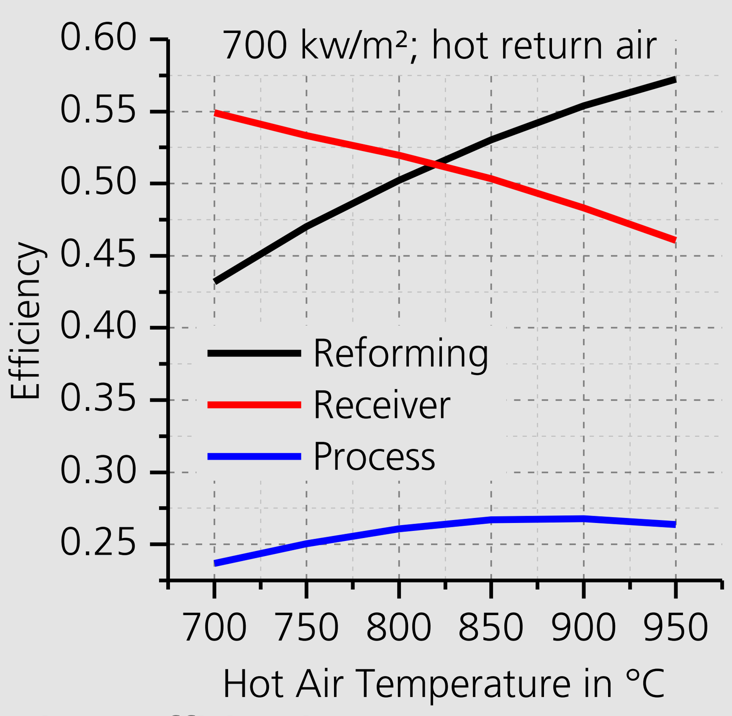

Fig. 6: Efficiencies over temperature

- Three forms of energy are involved. Definition of design point efficiency:

$$\eta_{Process,DP} = \frac{\Delta \dot{H}_{Gas}}{\dot{Q}_{intercept} + \frac{P_{El,net}}{0.34}}$$

$$\eta_{Process} = \eta_{Receiver} \cdot \eta_{Reforming}$$

- Conflicting behaviour of $\eta_{Receiver}$ and $\eta_{Reforming}$

→ Optimum for hot air temperature exists

Additional Air-Cooling, ARR and No. of Tubes

→ Additional air cooling („Cold") only benifitial for low ARR, for ARR > 0.4 direct return of air to receiver („Hot") is advantageous

→ Higher number of reformer tubes increase efficiency for both cases

→ Process effficiency increases significantly with ARR

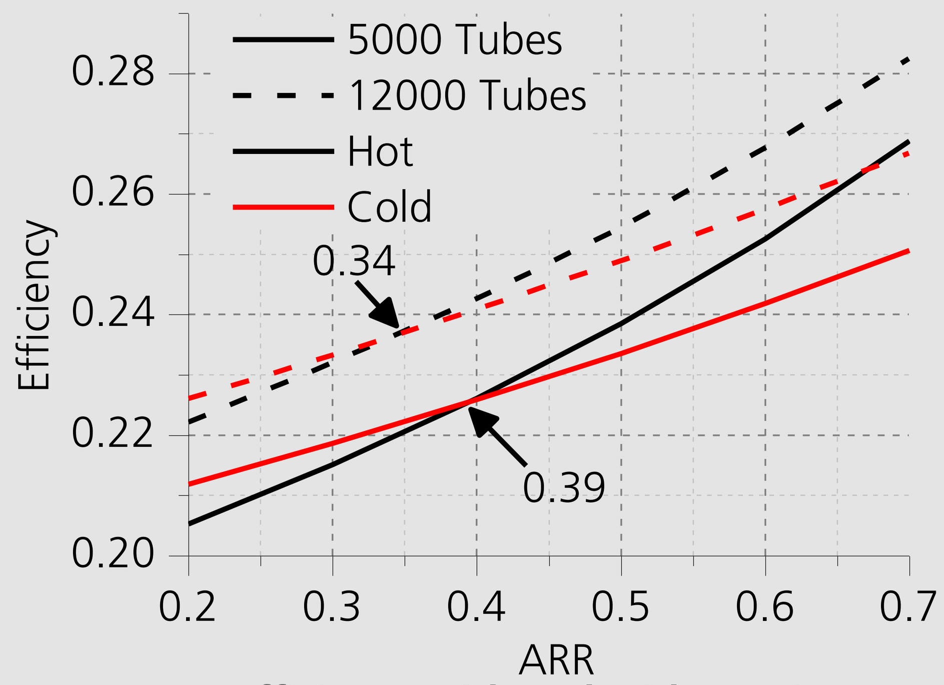

Fig. 7: Process efficiency with and without air cooling and different no. of tubes and over ARR

Conclusion & Outlook

- Solar reforming with open volumetric receivers has limited efficiency (27% in Design-Point, 16% annual)
- ARR has strong impact on overall efficiency
- Optimization of receiver for high temperatures and increase of ARR will enhance solar reforming efficiency.

Literature

Wesenberg, M. H.,2006, Gas Heated Steam Reformer Modelling. Faculty of Natural Sciences and Technology, Trontheim, Norway. Thesis, NTNU.

Pitz-Paal, R., 1993, Entwicklung eines selektiven volumetrischen Receivers fur Solarturmkraftwerke: Parameter-Untersuchungen und exergetische Bewertung, Cologne, Germany. Report, DLR.

Xu, J. and G. F. Froment, 1989, "Methane steam reforming, methanation and water-gas shift: I. Intrinsic kinetics." AIChE Journal 35(1): 88-96.

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