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SOLAR THERMAL ENERGY RESEARCH GROUP

Development of a dual-pressure air receiver for the SUNDISC cycle: Initial findings on the HPAR concept

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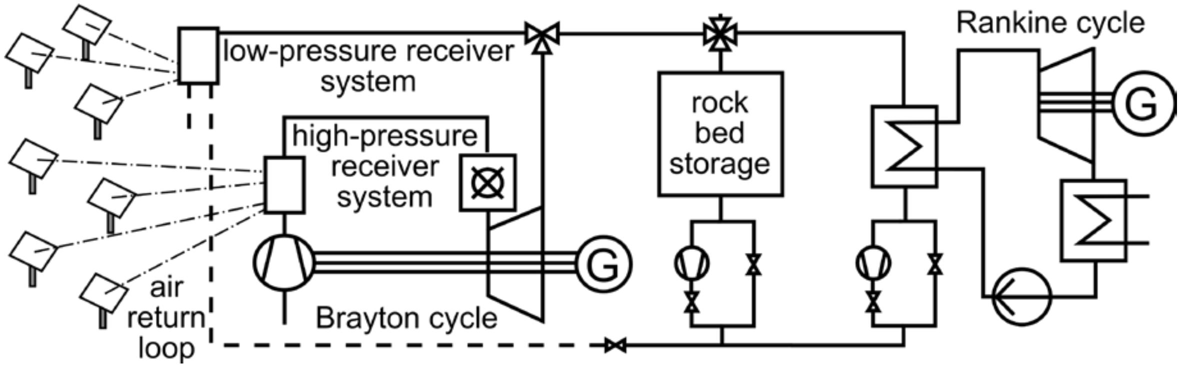
Introduction

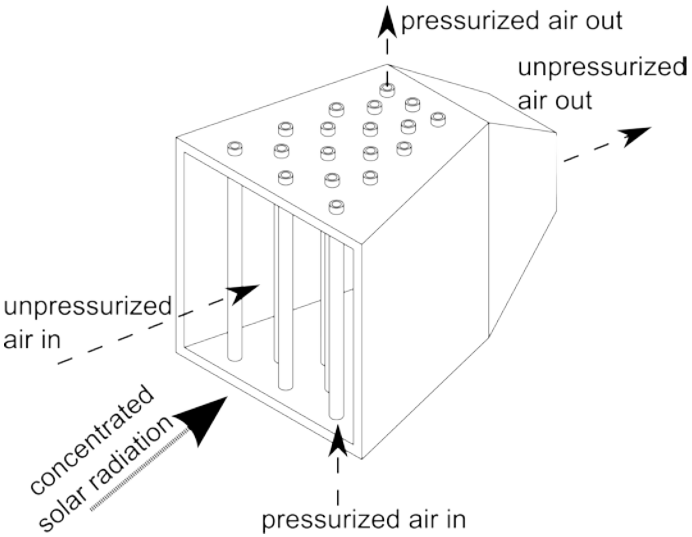
The SUNDISC cycle



- high cycle efficiency
- low co-firing rates
- ‘baseload’ characteristics
- cost-effective rock-bed TESS
- high capacity factor of pressurized receiver system

Introduction

The HPAR concept



- tubular metallic absorber
  - $T_{\text{out,max}} \approx 800\ °\text{C}$
- ‘macro-volumetric’ effect
- dual-cooling of absorber

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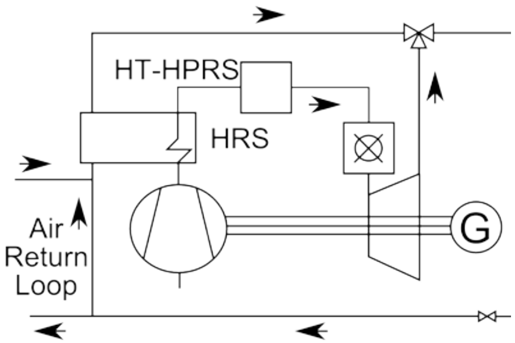
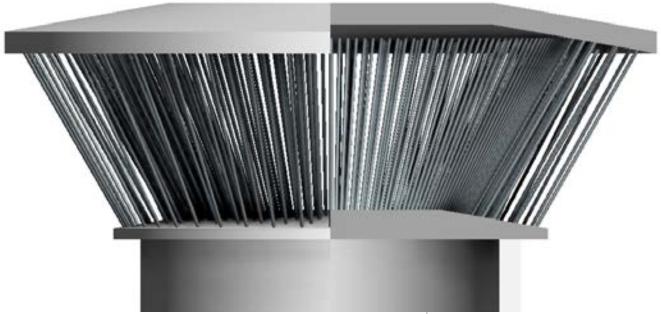
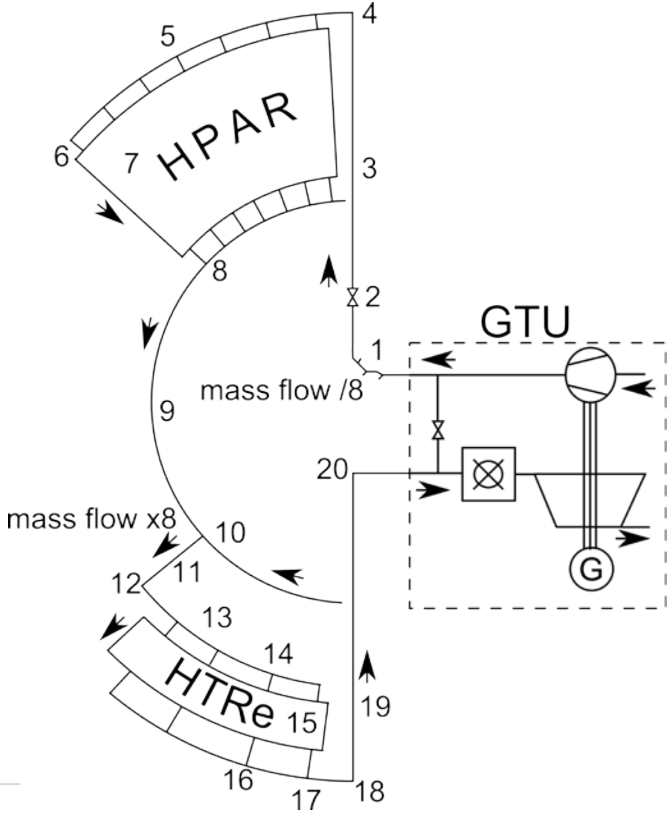
Implementation

Flow path



SOLGATE receiver
system (Buck, 2003)





Implementation

Boundary conditions for HPAR system (5 MW_e GT)

- $\dot{m}_{\mathrm{press.\,air}}$ = 20.5 kg/s
- p_{in} = 14.7 bar
- T_{in} = 400 °C
- T_{out} = 800 °C
- $\dot{Q}_{\mathrm{press.\,air}}$ = 9 MW_{t}
- $T_{\mathrm{tube,max}}$ = 950 °C
- $\Delta p_{\mathrm{HPAR,max}}$ = 100 mbar

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Modeling and First Findings

Optics – Modeling

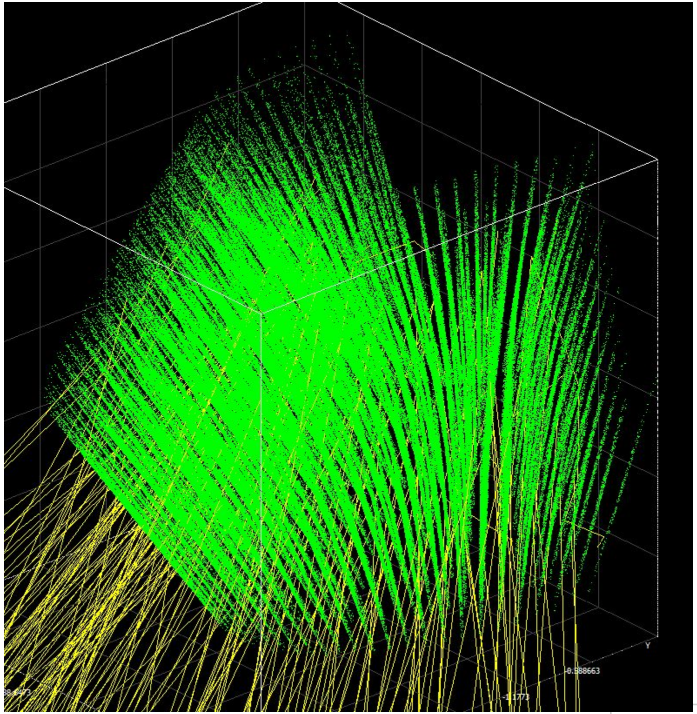
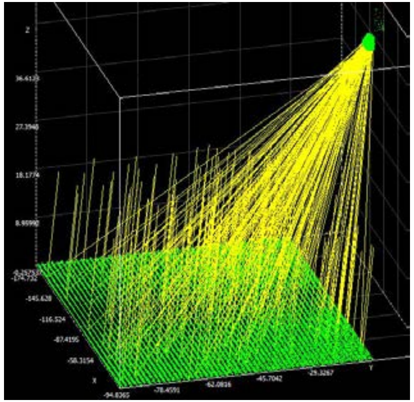


Photo of Sierra SunTower (adapted from Schell, 2011)

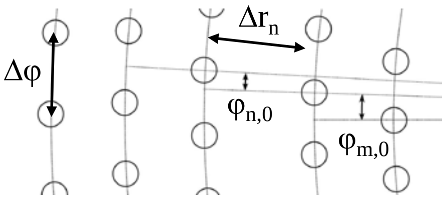
Visualization of hit points from HPAR ray tracing simulation

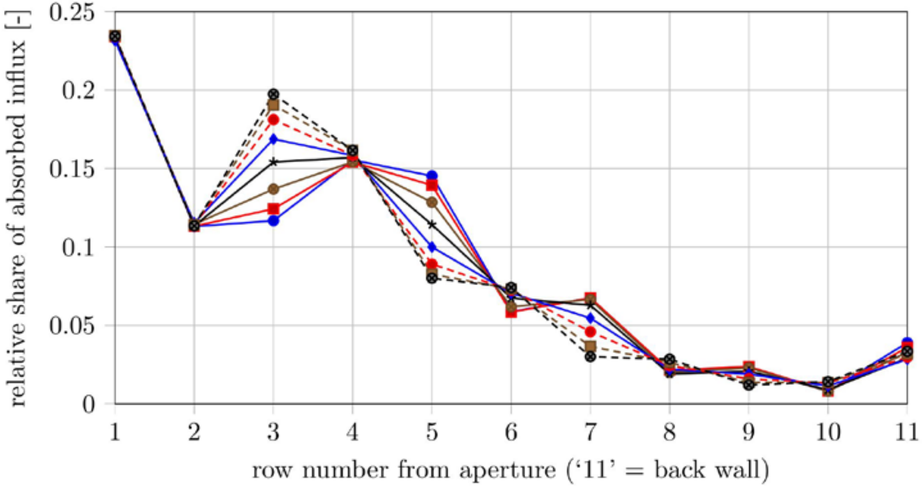


Modeling and First Findings

Optics – Findings

- flux distribution greatly influenced by tube layout
  - angular offset φ_0
  - distance Δr / $\Delta\varphi$
  - receiver tilt
  - wall design/properties
  - (solar field/sun position!)





flux penetration for differing angular offset between rows '2' and '3'

Modeling and First Findings

Thermal radiation – Modeling

Assumptions:

- infinitely long tubes
- same *T*-profile per row
- for radiation: tube has binary *T*-profile (front/back)

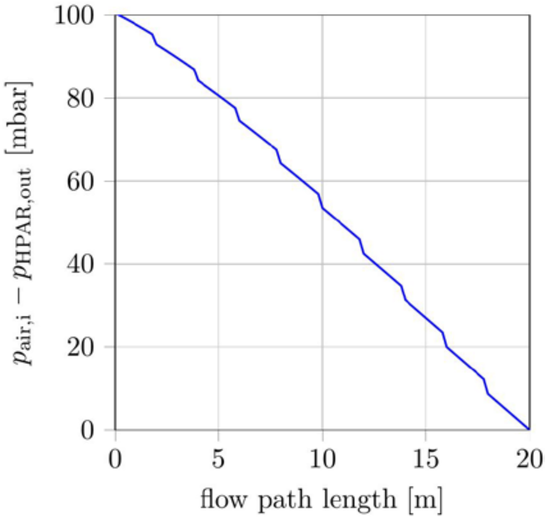
More detailed thermal radiation model should be applied (see Section 'Outlook')

Modeling and First Findings

Flow in tubes – Modeling

- Gnielinski correlation enhanced for circumferentially changing flux after Reynolds (1963) and Gärtner et al. (1974)
- chosen: D_i = 25 mm / L_{tube} = 2 m / n_{rows} = 10 (in series)

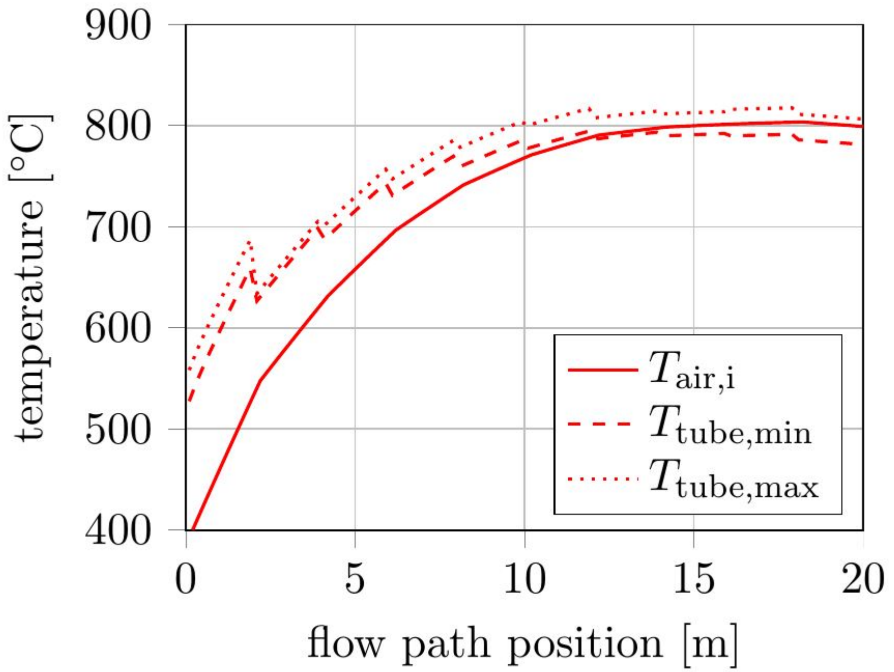
-> U_{mean} = 15 m/s
-> Re_{mean} = 40 000
-> $\dot{m}_{max}$ = 0.03 kg/s (per flow path/column)
-> Nu_{mean} = 83 / h_{mean} = 30 W/(m^2 K)



Modeling and First Findings

Flow in tubes – Findings

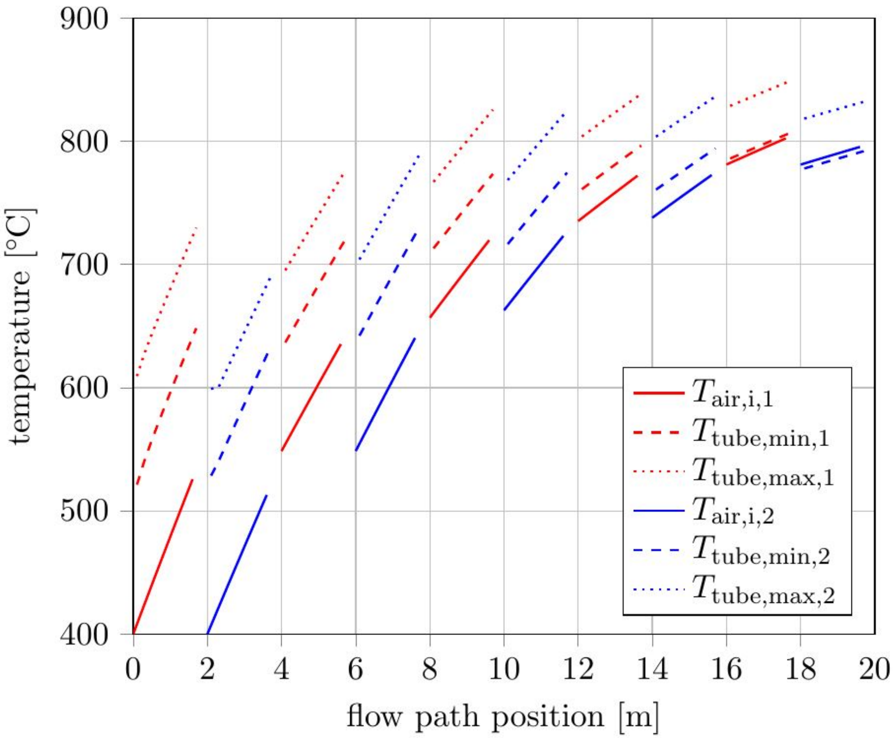
- serial flow path leads to low flow velocity and heat transfer
- $\dot{Q}_{\mathrm{Re}} = 1.11\ \mathrm{MW_t}$



Modeling and First Findings

Flow in tubes – Double flow path

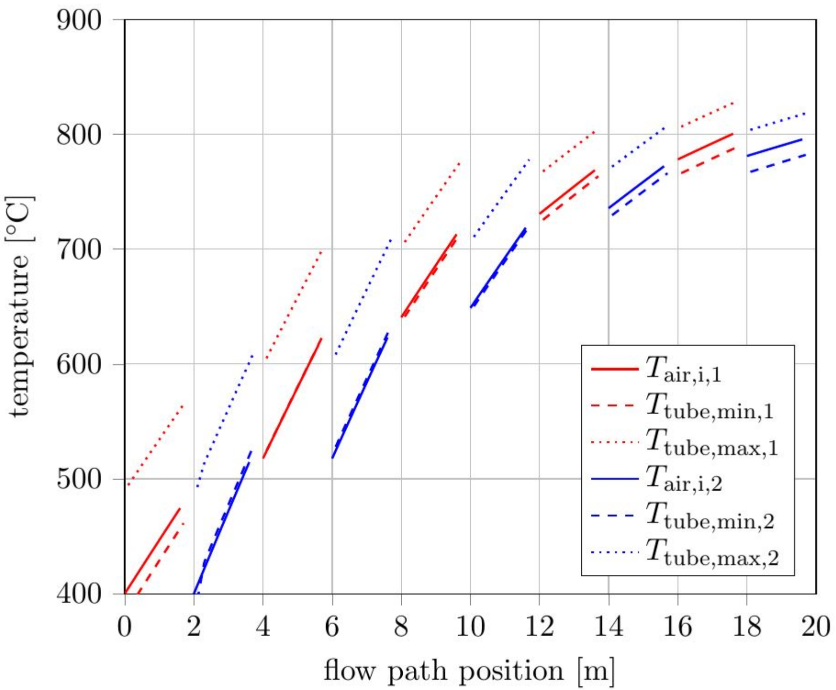
- partially parallel flow paths appears more favorable
- however, larger temperature difference occur between tube and air for higher air velocity
- $\dot{Q}_{Re} = 3.49\ MW_t$



Modeling and First Findings

Flow in tubes – Heat transfer enhancement (HTE)

- temperature difference between absorber (front) and air can be lowered by increasing heat transfer through HTEs at the cost of higher friction factors
- Chen et al. (2001) recommend dimples, Uhlig et al. (2015) tested corrugated tubes
- $\dot{Q}_{\mathrm{Re}}$ = 4.13 $\mathrm{MW_t}$



Modeling and First Findings

Flow around tubes – Modeling

- so far heat transfer modeled as flow around individual tubes only
- more detailed (3-D) model will be build in CFD

- For $U_{mean,o}$ = 4 m/s
  - $Nu_{mean,o}$ = 20
  - $\Delta T_{air,o}$ = 35 °C
- For $U_{mean,o}$ = 0.4 m/s
  - $Nu_{mean,o}$ = 6.3
  - $\Delta T_{air,o}$ = 102 °C
- wanted: $\Delta T_{air,o}$ > 400 °C

Modeling and First Findings

Flow around tubes – Findings

- heat transfer in tube bundle too poor to heat up considerable amount of air to desired temperature
- at lower velocities, wind will be problematic
- more elaborate modeling necessary but not expected to change the heat transfer to the needed extend
- external HTE or additional volumetric receivers at the inner wall are conceivable

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Outlook

- A CFD model will be created to conduct more detailed simulations of thermal radiation, heat transfer under circumferentially inconstant flux and heat transfer from the tube bundle to the unpressurized air stream
- additionally to the basic layout, the following enhancements will be investigated:
  - external HTEs
  - quartz glass inserts for radiation distribution and flow improvement

Thank you!

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References

Buck, R., 2003. Modularer Druck-Receiver für solarunterstützte fossile Gasturbinen- und Kombikraftwerke (REFOS-2) Schlußbericht. Stuttgart.

Chen, J., Müller-Steinhagen, H., Duffy, G.G., 2001. Heat transfer enhancement in dimpled tubes. Appl. Therm. Eng. 21, 535–547. doi:10.1016/S1359-4311(00)00067-3

Gärtner, D., Johannsen, K., Ramm, H., 1974. Turbulent heat transfer in a circular tube with circumferentially varying thermal boundary conditions. Int. J. Heat Mass Transf. 17, 1003–1018. doi:10.1016/0017-9310(74)90182-3

Reynolds, W.C., 1963. Turbulent heat transfer in a circular tube with variable circumferential heat flux. Int. J. Heat Mass Transf. 6, 445–454. doi:10.1016/0017-9310(63)90119-4

Schell, S., 2011. Design and evaluation of esolar's heliostat fields. Sol. Energy 85, 614–619. doi:10.1016/j.solener.2010.01.008

Uhlig, R., Gobereit, B., Rheinländer, J., 2015. Advancing Tube Receiver Performance by Using Corrugated Tubes. Energy Procedia 69, 563–572. doi:10.1016/j.egypro.2015.03.065