Sodium receivers

Sodium receivers for solar power towers: a review

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ASTRI
AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

Motivation for sodium receivers

- Liquid at high temperature ▶ high power cycle efficiency (Figure 1)
- High conductivity ▶ excellent heat transfer ▶ smaller receivers ▶ lower thermal losses ▶ improved efficiency
- Sodium most technically mature of the liquid metal candidates (cf. tin, lead-bismuth eutectic), fewer corrosion issues, extensive operational experience from the nuclear industry

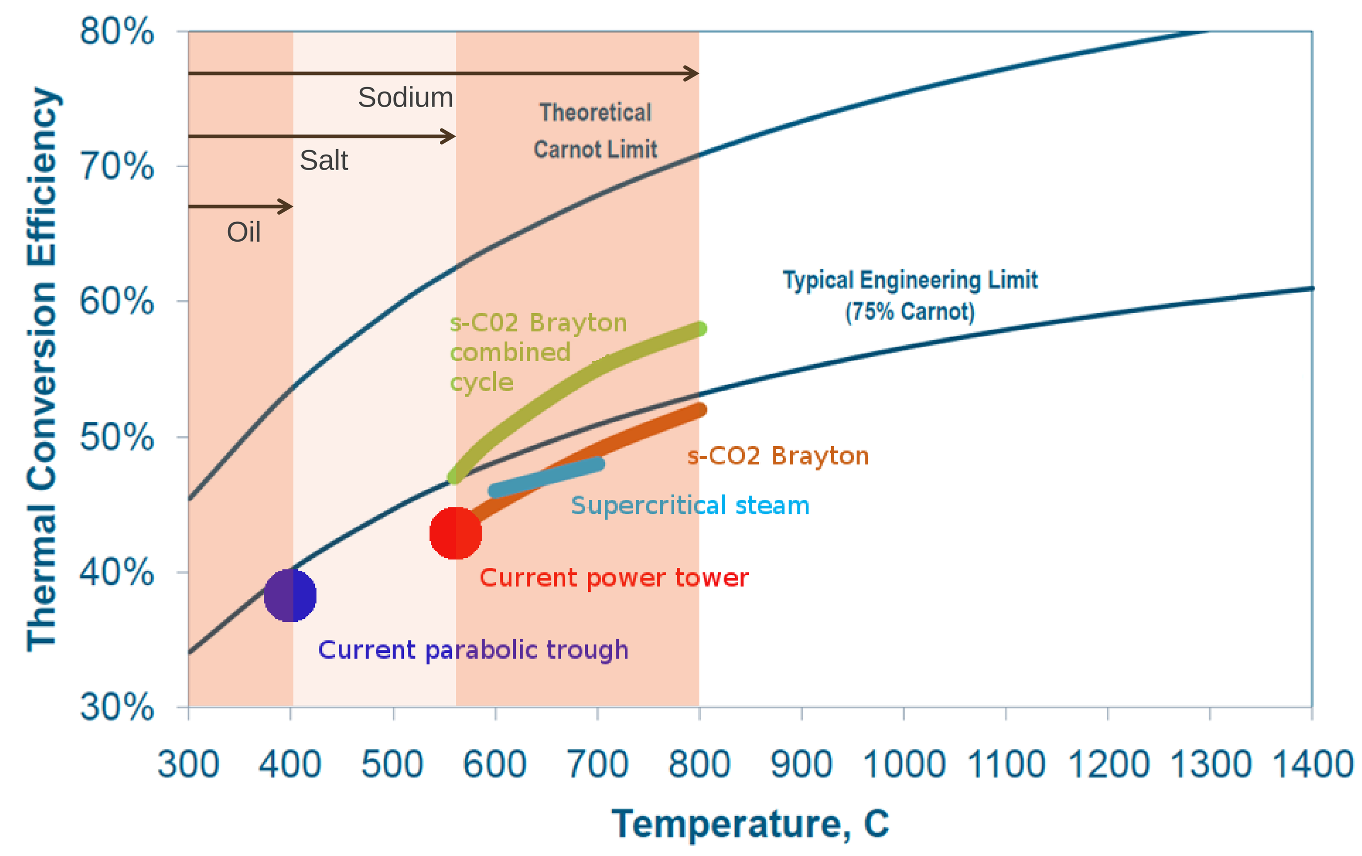

Figure 2: Thermal conversion efficiency vs operating temperature for various CSP technologies and power cycles. Source: modified from J. Gary, DOE-CSP Industry Meeting 2011

Sandia test program

- 75 hours testing during 1981-82
- 288°C/593°C inlet/outlet temperatures
- Solar flux up to 1.53 MW/m^2
- Receiver efficiency 90-96% ± 10%

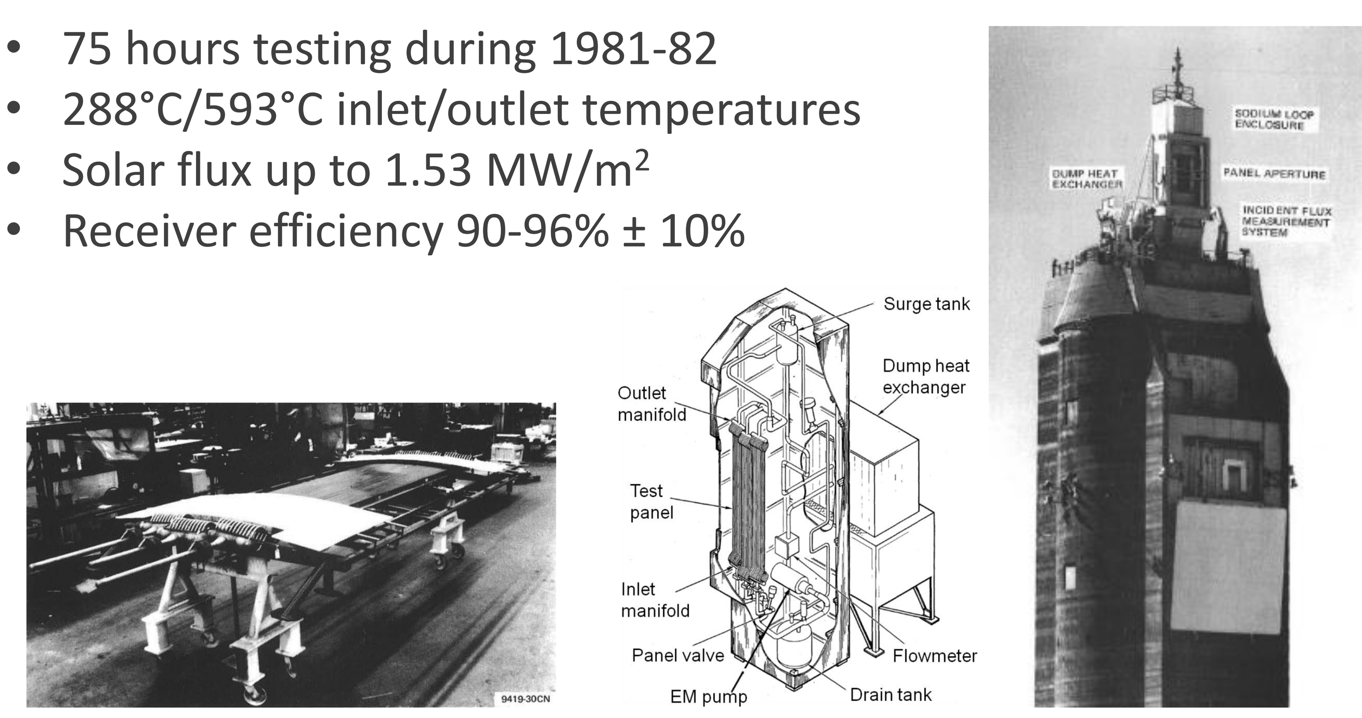

Figure 2: Assembled Rockwell test panel, ready for shipment to Sandia (left), the receiver and sodium test loop (centre) mounted on the Sandia Central Receiver Test Facility (right). Source: Sandia report SAND82-8192

Plataforma Solar de Almeria test program test program

'Sulzer' cavity receiver

- 1005 hours of operation in 1981-83
- 270°C/530°C inlet/outlet
- Peak flux in cavity of 0.63 MW/m^2
- Thermal efficiency
  - Daily average:76% (ITET), 67% (Sandia)
  - Instantaneous: 87% (Sandia)

'ASR billboard receiver

- 880 hours of operation in 1983-84
- 270°C/530°C inlet/outlet
- Peak flux of 1.4 MW/m^2
- Thermal efficiency
  - Daily average: 91.9% (ITET), 79.1% (Sandia)
  - Instantaneous: 96% (Sandia)

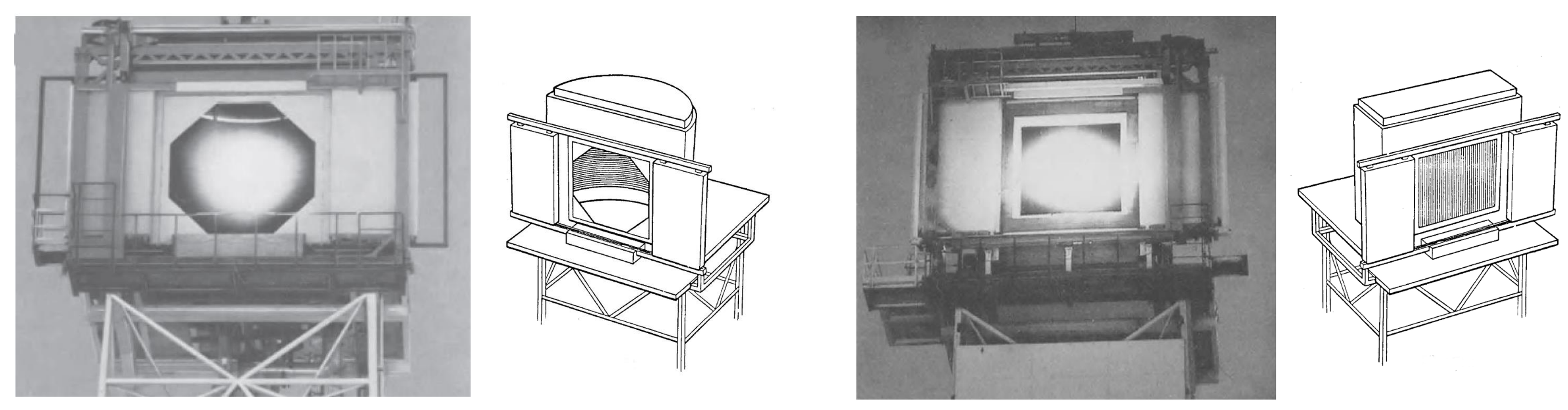

Figure 3: Sulzer cavity receiver (left) and ASR external receiver (right). Source: F. Casal, Solar Thermal Power Plants: achievements and lessons, Sandia report SAND87-8021

ASR High Flux Experiment

- Heliostat field re-focused with single aim point (tests in1985-86)
- Peak flux up to 2.5 MW/m^2
- At high flux a challenge is high peak absorber temperature due to poor conduction
  - Pipe wall and Pyromark were significant thermal barriers

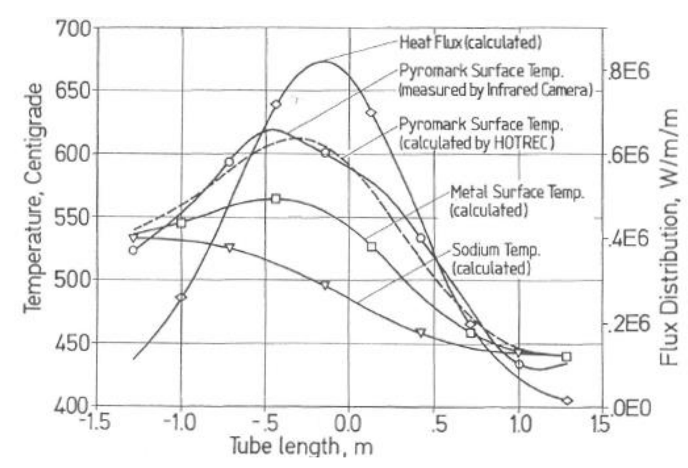

Figure 4: Comparison of simulation of surface temperature and measurements, for a tube in the peak flux region Source: Schiel et al. The IEA/SSPS High Flux Experiment, 1987

Vast Solar pilot plant

- Established a sodium test loop in 2012
- Modular tower system
- 2 m^2 flat billboard-style receiver, 700 heliostats, 25 m tower
- Power level of 1.2 MW_{th}
- 270°C/560°C inlet/outlet temperatures
- Peak flux of 1.5 MW/m^2

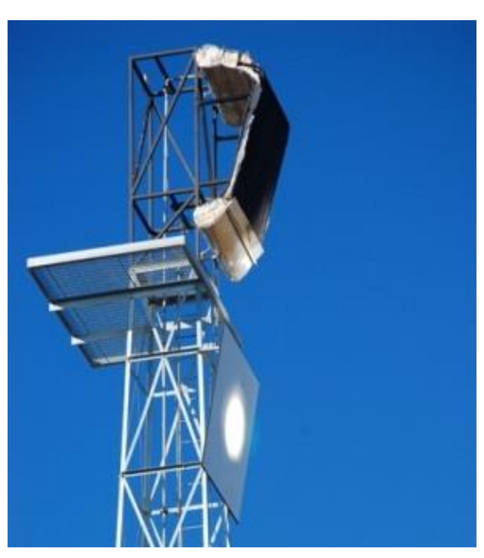

Figure 5: Vast Solar sodium receiver. Source: Vast Solar website.

Performance benefits

- Exergy analysis in the ASTRI P12 project provides insight into potential performance benefit due to the use of sodium as the heat transfer fluid
- Sodium has lower exergy destruction than molten salt due to internal convection BUT net exergy losses are similar
- Increasing the temperature range significantly reduces exergy loss in absorption BUT radiation losses increase significantly
- Increasing temperature AND solar flux has significant benefit (17% higher than the molten salt base case)
- The impact of reduced area is far more significant than the impact on losses due to the increased absorber temperature

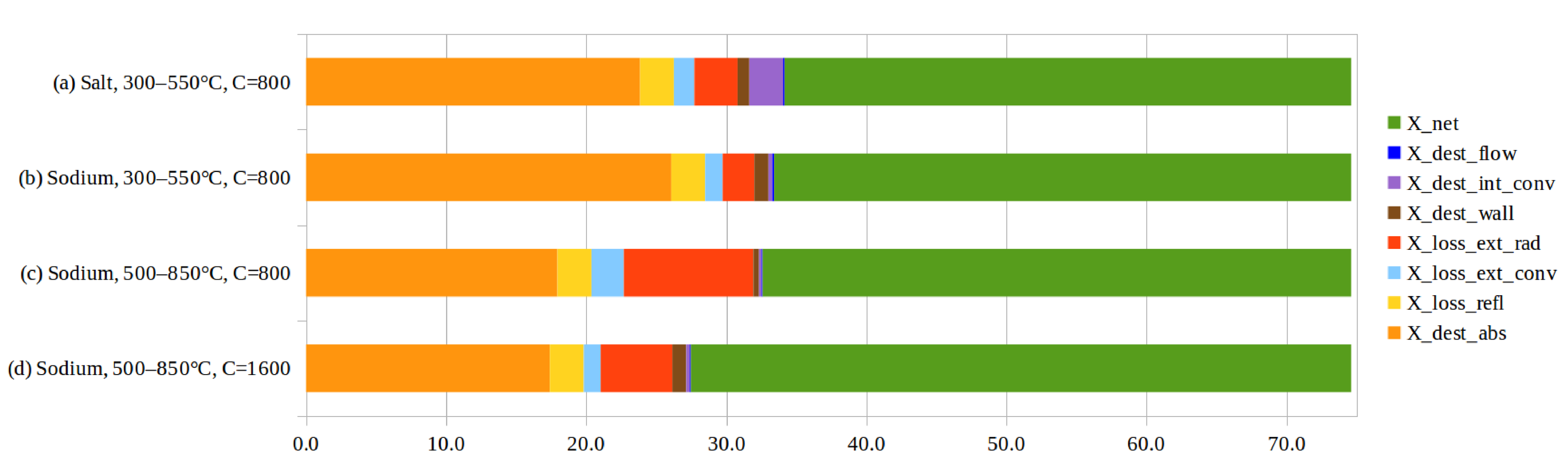

Fig. 6. Exergy balance for a) salt and b) sodium receivers with equal solar flux (C=800) and equal 300–550°C working fluid temperature range. Also includes c) sodium with 500–850°C working fluid range and d) sodium with both 500–850°C and C=1600. Source: Original, ASTRI P12 project

Risks

- Sodium is a hazardous material that reacts violently with water, and at elevated temperature, it may ignite in air in the absence of water
- August 1986, there was a sodium spray fire accident at PSA which halted sodium experiments at that facility and across the broader CSP field
- However, in the nuclear industry, there are now over 400 years cumulative operation of sodium-cooled reactors in plants at a scale of tens to hundreds of MWe, hence there is significant practical experience and many lessons have been learnt about liquid sodium safety.
- CSP can benefit from this experience.

Conclusions and planned work in ASTRI

- There are very positive performance results from large scale testing of sodium receivers at both Sandia and PSA in the early 1980's
- Sodium receivers are best suited to high-temperature, high-flux applications
- In the ASTRI P12 project we will develop a new tubular sodium receiver concept and test it in the ANU solar simulator and sodium laboratory
- We will examine novel ideas to minimise thermal losses, including quasi-cavity designs to improve light trapping
- The project is targeting efficiency of 91%+ at 700°C, a temperature suitable for driving a high-efficiency sCO_2 power cycle

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