Assessment of solar tower driven ultra supercritical steam cycles applying tubular central receivers with varied heat transfer media

C. Singer, R. Buck, R. Pitz-Paal, H. Müller-Steinhagen
Overview

- Motivation and Objective
- State of the Art
- Numerical Model
- Results
- Conclusions
- Future Work
- Time Schedule

Source: Sandia National Laboratories (modified)
Motivation and Objective

- USC parameters around 350bar and 720°C is the next development step
- A 55% thermal efficiency is within the potential of USC steam cycles
- CSP has the potential to clean and sustainable energy supply
  - relatively conventional technology
  - ease of scale-up
- Assessment of potential for solar tower driven USC cycles (50-1000MW_{el})
- Solar system options:
  - tube receiver
  - Beam-Down
  - Direct Absorption
  - Multi Tower Solar Arrays
  - and combinations

Source: F. Téllez, CIEMAT
State of the Art

- 360° cylindrical receiver, Solar Salt (290°C-565°C)
- Solar Tres (Basis for the assessment)
  - 17MW_{el} / 15h storage capacity / Fuentes de Andalucia (Sevilla, Spain)
  - steam power cycle (38% thermal efficiency)
- Solar 50 (Reference of the economical assessment)
  - 50MW_{el} / 8h storage capacity / Fuentes de Andalucia (Sevilla, Spain)
  - steam power cycle (44% thermal efficiency)

Innovations

- Solar USC
  - supercritical power cycle (350bar / 720°C / 53% thermal efficiency)
- HTM
  - tin, sodium, bismuth-lead or. bismuth-tin and LiCl-KCl eutectic
Assessment Workflow

Solar Field Layout
- Field Characteristic
- Number of Heliostats
- Tower Costs
- Field Characteristic
- Receiver Size
- Flux Distribution
- Receiver Characteristic
- Receiver Costs

Receiver Design

Assumptions (Site, Geometry, Costs, etc.)

Annual Performance

LEC
Numerical Model - number of serial panels

- Mod. n
- Tmax
- Mod. 3
- Mod. 2
- Mod. 1
- Tmin
- HR
- Perimeter

Legend:
- Reflection
- Incident Flux
- Radiation
- Forced convection (wind)
- Free convection

Graph:
- Receiver efficiency incl. parasites
- Levelized irradiation flux / 1=DP
- Temperature T_min

Images:
- Symmetry axis
- n=odd
- n=even
- Perimeter

Foil 6
Results - performance due to number of serial panels

Without HTM pumping parasitic losses

With HTM pumping parasitic losses

Note: The number of serially flow-through panels has a significant influence on the plant performance
Results - performance due to number of serial panels
Results - LEC due to number of serial panels

NaNO₃-KNO₃

Sn

Note: The number of serially flow-through panels has a significant influence on the plant performance, even more if the cooling takes place with liquid heavy metal.
Results - annual performance and LEC sensibility

- **HTM**
  - NaNO3-KNO3: 8h, 0% LEC
  - LiCl-KCl: 12h, 10% LEC
  - Sn: 8h, 12% LEC
  - Bi-Pb: 12h, 7% LEC
  - Na: 12h, 10% LEC

- **Relative LEC**
- **Relative component costs**

- **Legend**
  - solar field
  - receiver
  - power block
  - storage
  - tower

- opt. storage capacity [h] / opt. number of panels []
- storage capacity [h] / opt. number of panels []
Conclusions

- significant LEC reduction potential of
  - about 15%, if USC, liquid metal, optimum storage size is assumed
  - about 10% if equal storage sizes are compared
- HTM with higher thermal conductivity leads to lower LEC
  - due to the reduction of radiation loss at the central receiver,
  - if the storage cost is independent of the used HTM costs
- The assessed liquid metals provide a significantly better receiver performance
  - however, these HTM are too expensive for the usage as storage medium
- No salt mixture or liquid metal is available in the cost range of solar salt without decomposition in the required temperatures range for USC
- High temperature receiver loop with a separate storage material tends to be more cost effective for future solar applications