HPS2 – High Performance Solar 2

Évora Molten Salts Platform

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Content

1. Motivation
2. History of the Project
3. HPS2 Objectives
4. Design and Opportunities of demonstrator
5. Summary
Molten Salt Heat Transfer Fluid in Parabolic Troughs

Advantages
- Direct storage of collected heat
- Full de-coupling of solar field operation from power production
- No unforeseen fluctuations on power block and grid

Challenges
- Freeze protection at 220°C in whole collector and piping system
- Overnight heat losses
- Corrosion / material selection
- Salt mixtures with low melting point
Molten Salt in Parabolic Trough
Current activities

Italy: Archimede Solar
• 2010: 30 MW$_{th}$ Parabolic trough field delivering heat to combined-cycle power plant k
• 2013: 2 MWth molten salt testloop (3.600 m)

Source: Archimede Solar Energy
Thermal oil (state-of-the-art) vs. Molten Salt Technology

• CSP Solar Power Plants have the purpose to produce CO2-free, renewable and **dispatchable** (in comparison to PV plants) electricity

• Dispatchability is only achieved using a thermal energy storage

• Comparison of state-of-the-art-technology with molten-salt-technology:
  
  • Life steam parameters and power block efficiency:
    • State-of-the-art: 386 °C / 100 bar: **39,2%**
    • Molten salt: 550 °C / 150 bar: **45,5%**
  
  • HTF-pump auxiliary load:
    • State-of-the-art: 6-7 %
    • Molten salt: 1-2 %
  
  • Volume of thermal energy storage at same capacity:
    • State-of-the-art: 100 %
    • Molten salt @550 °C: **36 %**
  
  • Direct storage of HTF opens fully independent operability of solar field and power block
Influence of Collector type on Levelized Costs of Electricity

Reference plant in Spain:
- 125 MW
- HTF: NaK-NO3-Technologie@530°C
- 8h-storage
- Collector types:
  - Ultimate Trough (7.5m)
  - Euro Trough (5.6 m)

LCoE-Reduction of UltimateTrough vs. EuroTrough:
23.2%

Total LCoE reduction potential of state-of-the-art-plants (thermal oil, 5.6 m troughs) and future technology (molten salt, 7.5 m troughs):
33.2%
Potentials (LCoE – Roadmap)

LCoE evaluation over technologies

Potentials of Molten Salt Technology
What do other people say?

Kearney et al. (2003):
LCoE Potential between 14,2 and 17,6%
VP1 vs. NaK or HiTec XL

Kelly et al. (2007)
LCoE Potential up to 25%
VP1 vs. NaK with 8m aperture

Kolb, Diver (2008)
LCoE Potential between 6 to 25%
VP1 vs. NaK and 2X-Trough (high aperture)

Turchi et al. (2008)
LCoE potential of 21 up to 45%
VP1 with 6h-storage vs. NaK with 6h-TES and 450 °C vs. NaK with 12h-TES and 500 °C

Riffelmann et al. (2011)
LCoE potential of 11,6%
EuroTrough (5,7 m) vs. UltimateTrough (7,5 m) (both mit VP-1)

Giostri et al. (2012)
Increase of annual energy output of 6%
VP1 vs. NaK without storage
What hinders the technology?

Or the „10 major concerns“:

1. Filling and draining of the plant
2. High thermal effort during anti-freeze operational mode (added costs for the required heating)
3. Danger of freezing during various operation modes
4. Blackout scenarios
5. Material requirements, high corrosion
6. Performance of the SCA / HCE
   a. thermal performance, b. optical performance, c. mechanical properties
7. Flexible connection: Proof of functionality and tightness
8. Steam Generating System: internal leakage due to defect of heat exchanger tubes
9. Maintenance procedures, Handling of disturbances (e.g. complete draining and re-filling)
10. Stability of salt mixtures (time stability, thermal stability)
History of the HPS-Project

In 2010 a consortium of industry and research institutes joined to set up a demo plant under the funded project HPS.

The partners were Siemens (as project leader), DLR, Steinmüller Engineering, K+S and Senior Flexonics.

In 2012 Siemens decided to step out of the solar business. A total volume of approx. 5 Mio € was invested.

The plant was overtaken by University of Évora in 2013
Co-operation agreement between University of Évora and DLR to jointly complete and operate the Evora Molten Salt Platform
Plant Layout

- Steam Generating System
- DCS/PCC/MCC
- W/S-Cycle
- Thermal Energy Storage
- Drainage Tank with Melting Unit
- Solar Field Site
- Wind Fence

Civil Works, Site power and Water Treatment

Plant fully completed
Objectives of HPS2 project

The project HPS2 aims to erect, operate and demonstrate
- a parabolic trough system with an aperture of 6.8 m
- two-tank storage systems
- once-through vessel (design 550 °C/150 bars)
with the technology fully based on Molten Salt as heat transfer medium

This set-up will be a first-of-its-kind demo plant world wide
Technical Specifications

Remark: Specs according to design layout with Solar Salt

Helio Trough
- Solar Field Design Power: 2.8 MW
- Aperture Width: 6.8 m
- Length of single collectors: 191 m
- Number of Collectors: 4
- Thermal Efficiency: ~70%

Once-Through SGS
- Steam Generating System: 1.6 MW
- Life Steam Design Temperature: 560 °C
- Life Steam Design Pressure: 140 bar

Thermal Energy Storage
- Storage Capacity @ $\Delta T=280$ K: 2 hours
- Tank Height: 5.0 m
- Tank Diameter: 3.1 m
Testing options

1. Filling and draining of the plant

Drainage Tank designed to accept total content
Solar field piping and steam generator

Drainage options and foreseen tests:
- Drainage of horizontal piping: self-draining
- Drainage supported by pressurized air system
- Partly drainage and subsequent re-melting by trace heating
- Drainage points in-between collectors
- Drainage mass flow measurements
- Pneumatic Valves in solar field and storage system
- System prepared for „Salt Dilution“
Testing options

2. High thermal effort during AF operation

Complete protection of salt piping and equipment with trace heating.

Anti-Freeze-Options and foreseen testing:
- Several different options of trace heating implemented
- Storage design enables complete night operation from storage
- Solar-driven convective anti-freeze operation
- Electric-powered anti-freeze operation
- Drainage for freeze protection
- Monitoring of energy demands of subcomponents
Testing options

3. Danger of freezing during various operation modes

- Numerous temperature measurements in all system
- Heat loss measurements in storage foundations
- Sufficient and redundant trace heating
- Insolation and heating based on analysis of operating modi
- Avoiding of stagnating liquid salt in all operating conditions
- Automatic operation of trace heating systems
- Instrumentation to analyse heat losses of all individual subcomponents
Testing options

4. Blackout scenarios

- System design and operation close to upper temperature ensuring operational flexibility in case of emergency
- Uninterrupted power supply with battery und diesel-generator
- Simulation of scenarios within T3000-controlsystem (Single components as well as complete system, including different back-up power systems)
- Automatisation of blackout procedures
Testing options

5. Material requirements, high corrosion

• Corrosion tests with external specialists
• Appropriate material selection
• Good access to all components and piping to enable sampling
Testing options

6. Performance of the SCA

• Loop instrumentation with numerous flow- and temperature measurements
• Optical and thermal qualification tests and documentation during acceptance
• Central data acquisition system, data storage over whole project period
• Redundant instrumentation at sensible points
• Weather station including cloud camera system
7. **Flexible connection**

- Test of flexible connection to compensate thermal expansion and rotation
- Decentral drainage option
- Proof of reliable trace heating to avoid freezing
- Alternative solution without rotational joint
- Torsion measurements
Testing options

8. *Steam Generating System: internal leakage due to defect of heat exchanger tubes*

- Salt-heated
  - Benson boiler (150 bar/550 °C)
- Background from Solar Two
- Adapted design and operation
- Safety system implemented
Testing options

9. **Maintenance procedures**,  
   **Handling of disturbances**

- Draining options for all subcomponents independent from operating modus
- Single storage tank volume designed to accept total system volume: Salt management options
- De-mineralised water production on site (steam generator and mirror washing)
- Highly flexible control system with automatisation options
- Redundant design of main pumps and important control instruments and actuators
Testing options

10. Stability of salt mixtures

- Full accessibility to storage tanks
- Laboratories for salt analyses available at project partners
- Redundant level measurements with different methods in all tanks
- NOx-measurements in the gas blanket
Summary
Evora Molten Salt Platform

- Unique infrastructure to demonstrate solutions to all major concerns against molten salt in parabolic trough systems

- Options for test of innovative solutions for design or operation e.g. optimized drainage or freeze protection operations

- Demonstration of ability of project consortium to provide advanced technology for first commercial implementation

- Extension potential for implementation and test of alternative technologies

- Chance to collect operational knowledge and create competitive advantages
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