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Technical Requirements for Concentrating Solar Thermal Systems Materials

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Concentrating Solar Thermal Systems

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- Brief introduction to the CST Systems
- Advanced materials for CST Systems
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Concentrating Solar Thermal Systems

What is a Concentrating Solar Thermal (CST) System?

A CST system collects and concentrates the direct solar radiation to convert it into thermal energy at medium/high temperature (even higher than 2000ºC). This thermal energy is then used to either feed an industrial thermal process or produce electricity.

Why concentration?

Concentration is required to compensate for the great attenuation suffered by the solar radiation in its way from the Sun (63 MW/m²) to the Earth (1 kW/m²).
Concentrating Solar Thermal Systems

Efficiency versus Concentration Factor

\[ \eta = f(C, T) \]

Dependence of the Efficiency and the Optimum Working Temperature on the Solar Radiation Concentration Factor
Concentrating Solar Thermal Systems

What is a Concentrating Solar Thermal (CST) System?
A CST system collects and concentrates the direct solar radiation to convert it into thermal energy at medium/high temperature (even higher than 1000ºC). This thermal energy is then used to either feed an industrial thermal process or produce electricity.

Why concentration?
Concentration is required to compensate for the great attenuation suffered by the solar radiation in its way from the Sun (63 MW/m²) to the Earth (kW/m²).

CST technologies:
There are four different CST technologies:

- Central receiver plants
- Parabolic trough collectors
- Stirling dishes
- Linear Fresnel concentrators
CST Technologies

Central Receiver Technology

Receiver

Heliostat field

Tower

Power Conversion System

100 m
CST Technologies

Parabolic Trough Collectors
CST Technologies

Solar Power Plant with Parabolic Trough Collectors

Solar field

Power Conversion System
CST Technologies

Stirling Dish

Typical Stirling Dish

Concentrator

Receiver

Estructure

Stirling engine
CST Technologies

Linear Fresnel Concentrator

Receiver pipe

Rectangular reflectors
Plataforma Solar de Almería (PSA) is the largest public R&D center in the World devoted to CST technologies.

Aerial view of the PSA experimental facilities (www.psa.es)
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Advanced Materials for CST Systems

CST systems need advanced materials for extreme conditions in order to reduce cost and/or increase efficiency:

- **Special Coatings:**
  - Selective coatings for solar receivers
  - Anti-reflective coatings for quartz windows

- **Advanced raw materials for Central Receivers**

- **Advanced materials for thermal storage at high temperatures (>700ºC)**

- **New working fluids for temperatures >650ºC**
Advanced Materials for CST Systems

Selective coatings for solar receivers

Solar receivers transform the concentrated solar radiation into thermal energy. There are two different groups of receivers

a) Linear Receivers (receivers for parabolic troughs and linear Fresnel concentrators)

- High absorptivity (>95%) and low emissivity (ε≤0.15 at 500°C)
- Stable in hot air at 600°C and with thermal cycles from ambient to 600°C
- Solar flux of about 75 kW/m²
Advanced Materials for CST Systems

- **Selective coatings for solar receivers**
  
  Solar receivers transform the concentrated solar radiation into thermal energy. There are two different groups of receivers

b) Central Receivers (receivers for solar tower systems)

- High absorptivity (>92%) and low emissivity ($\varepsilon \leq 0.35$ at 800°C)
- Stable in hot air at 800°C
- Solar flux of about 1 MW/m²

View of a Tube-bundle solar receiver

Central receiver in operation
Advanced Materials for CST Systems

- **Anti-reflective coatings for quartz windows**
  - Quartz windows are commonly used for cavity-type central receivers

**Challenges:**

- good durability in outdoor conditions,
- easy to produce
- durable at temperatures of about 800°C.

![Typical quartz window used in cavity-type receivers](image)
Advanced Materials for CST Systems

- Advanced raw materials for Central Receivers
  - Receiver types:
    - Tube, Volumetric
  - Receiver raw material:
    - Steels: for tube and volumetric receivers
    - Ceramics: for volumetric receivers

- Tube-bundle solar receiver
- Metallic volumetric receiver
- Ceramic volumetric receivers
Advanced Materials for CST Systems

- **Advanced raw materials for Central Receivers**

  **Challenges:**

  - Working temperatures higher than 1000°C (steels) or 1200°C (ceramics)
  - Solar fluxes > 1 MW/m²
  - Long durability under thermal cycling
  - Good thermal conductivity
  - Affordable cost

Advanced Materials for CST Systems

➢ Advanced materials for thermal storage at T>700ºC

Thermal storage materials currently used:
- Thermal oils (up to 300ºC)
- Molten nitrate salts of sodium and potassium (up to 575ºC)
- Ceramics (alumina) (up to 800ºC, low thermal conductivity)

Challenges:
- High heat capacity, thermal conductivity and working temperature
- Low thermal expansion
- Long durability under thermal cycling

View of typical 2-tank thermal storage system with molten salts
Advanced Materials for CST Systems

- **New working fluids:**

  **Working fluids currently used:**
  - Thermal oils (parabolic trough collectors with T≤400°C)
  - Water/Steam (linear Fresnel with T≤300°C and central receivers with T≤550°C)
  - Molten Salts (central receivers with T≤575°C)
  - Air (central receivers with T≤800°C)

- **Challenges:**
  - High heat capacity and working temperature
  - Long durability under thermal cycling
  - Low viscosity
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CST Systems for R&D on New Materials

There are two CST systems that are very useful to evaluate the performance of materials in extreme conditions:

- Solar Furnaces

![Scheme of a typical Solar Furnace](image)

![View of the PSA SF-60](image)
There are two CST systems that are very useful to evaluate the performance of materials in extreme conditions:

- Solar Furnaces
- Solar Towers

Solar tower system with the heliostats in stand-by position
CST Systems for R&D on New Materials

Use of Solar Furnaces and Towers for materials testing

Direct application of highly concentrated solar radiation to materials

- Flux density up to 7000 kW/m² (and more)
- Very high temperatures >2000ºC
- Extreme operating conditions

Materials treatment and caracterization
- Thermal Shock Tests
- Thermal cycling

Tests in air, vacuum and in controlled atmosphere conditions (i.e. Ar, N₂, N₂/H₂)
PSA Solar Furnaces for Materials Testing

**SF60**
- Power: 60 kW
- Peak Concentration: 3000 kW/m²
- Focus Size: Ø 25 cm
- Focal Distance: 7.45 m

**SF40**
- Power: 40 kW
- Peak Concentration: 7000 kW/m²
- Focus Size: Ø 10 cm
- Focal Distance: 4.5 m

**SF5**
- Power: 5 kW
- Peak Concentration: 7000 kW/m²
- Focus Size: Ø 2.5 cm
- Focal Distance: 2 m
Research in the field of **surface treatment**, characterisation of metallic and ceramic materials and thermal shock tests.

Materials Treatment and High Temperature Solar Heat

Research in the field of **material treatments**, solar heat processes at high temperature and solar chemistry.

- **MiniVac Chamber**
- **Solar Processing chamber**
- **Solar Fluidized bed**
- **Solar Rotary kiln**

- **Thermal Shock Tests**
- Sintering
- Carburization
- Nitridization
- Foaming
- Quenching
- Sintering of nanostructured materials...

- **Testing of**
  - Concentrating PV Cells

- **Fire of ceramic tiles**

- **Steel Hardening and Tempering**
  - Sintering of aluminium
  - Aluminium Foaming
  - Reduction of iron oxide to magnetite
  - Catalytic Decomposition of CH$_4$

- **Solar thermal remediation of contaminated soils**
  - Thermochemical production of H$_2$
  - Reduction of ferrites

- **Flux density up to 700W/cm$^2$**
- Temperatures up to 2000 °C

TESTS IN AIR AND IN CONTROLLED ATMOSPHERE (Ar, N$_2$, N$_2$/H$_2$)
Conclusions

• CST technology needs new Advanced Materials

• Existing CST facilities (solar towers and solar furnaces, mainly) are very suitable for materials testing in extreme conditions
Thank you for your attention!!

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