Parabolic Trough Receiver
Thermal Performance

Parabolic Trough Workshop

Golden, Colorado

March 9, 2007
Key to good performance at parabolic trough power plants

- Problems with glass breakage appears to be resolved with new designs and O&M procedures.
- New receivers improve optical and thermal performance.
Parabolic Trough Receiver or Heat Collection Element

New Solel UVAC Receiver

- Borosilicate Glass Tube
  - w/ Anti-Reflective Coating
- Stainless Steel Tube
  - w/ Cermet Selective Coating
- Getters to Absorb Gases
  - (Hydrogen)
- Protective Shielding for Glass-to-Metal Seal

New Schott Bellows

Bellows & Glass-to-Metal Seal
**Parabolic Trough Receiver Thermal Testing**

- **Outdoor – Thermal Loop Tests**
  - Use measurement of flow and temperature difference to calculate energy gained or lost.
  - Sandia Rotating Platform, Plataforma Solar de Almería EuroTrough Collector, SEGS Collector Test Loops

- **Indoor**
  - Electric resistance heating
    - Heat receiver to steady state temperature
    - Electric power consumed is the thermal loss
  - DLR, Schott, ENEA, NREL
Parabolic Trough Receiver Thermal Testing

- Receiver testing on AZTRAK rotating platform @ Sandia
  - Luz Black Chrome (1993)
  - Luz Cermet (1993)
  - Solel UVAC (2003)
  - Schott Cermet (2004)
- Advantages
  - 2-Axis Tracking
  - On-sun or off sun testing
- Disadvantages
  - Only one collector element tested & 2 receivers
  - Low precision on measurements
Efficiency vs. Average Fluid Temperature Above Ambient for the LS-2/Schott HCE system

Efficiency (%) vs. Average Fluid Temperature Above Ambient (°C)

Curve fit equation:
\[ \eta = 78.59 - 0.0357T - 4.33 \times 10^{-6}T^2 \]

at about 1000 W/m² DNI
Parabolic Trough Receiver
Thermal Testing

• Receiver testing on EuroTrough Prototype @ Plataforma Solar de Almería
  • Solel UVAC
  • Schott Cermet
• Advantages
  • Full collector tested (more receivers)
  • Better precision
• Disadvantages
  • Single E/W axis tracking
  • Reduced test flexibility
• Receiver testing on ENEA Loop
  • Schott Receiver
  • ENEA Receiver (Summer 2007)
• Advantages
  • Molten Salt Test
  • Higher Temperatures
  • Two Collectors
Loop Testing at the SEGS
  - Solel UVAC (SEGS VI)
  - Schott Cermet (SKAL-ET, SEGS V)

Advantages
  - Field testing in normal operation
  - Full loop tested
  - Comparison to other loops

Disadvantages
  - Many factors affect results
  - Limited control of test
UVAC / Cermet Comparison - SEGS VI

Thermal Efficiency - %

Insolation - W/m²

- UVAC Loop (3/4)
- Base Loop (5/6)
- Insolation

3/28/01
**DLR Receiver Test Lab**

- Electric resistance heating
- At steady state power consumption is equal to thermal losses
NREL Receiver Test Lab

- Electric resistance heating
- At steady state power consumption is equal to thermal losses
- Similar to approaches used by DLR & Schott

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Receiver Test Results

Solel UVAC 2

Loss (W/m) = \(0.47 \Delta T + 6.11 \times 10^{-9} \Delta T^4\)

Thermal Loss \((W/m)\) in liquid cool-down tests, \(T^* = T_{fluid}\)

Thermal Loss \((W/m)\) in electric resistance testing, \(T^* = T_{absorber}\)
Receiver Test Results
Schott PTR70

Thermal Loss (W/m HCE length)

Thermal Loss (W/m² collector aperture)

NREL PTR70 (2007)
--- Loss (W/m) = 0.39*ΔT + 1.21E-08*ΔT^4
Sandia PTR70 (2005)
--- Loss (W/m) = 0.26*ΔT + 9.50E-09*ΔT^4
EuroTrough PTR70 (2004)
--- Loss (W/m) = 0.33*ΔT + 1.54E-08*ΔT^4
Thermoc PTR (2004)
--- Loss (W/m) = 0.33*ΔT + 1.16E-08*ΔT^4

HCE length = 4.08 m
Collector holds 2 HCEs
Collector aperture area = 39.2 m²

T* - T_ambient (°C)

in liquid cool-down tests, T* = T_fluid
in electric resistance testing, T* = T_absorber
Receiver Field Survey
With Infrared Camera

- Cool Receiver
- Hot Receiver
- Temperature Varies

Sky
Receiver
Mirrors
For a known wind speed and ambient temperature, ...

- Receiver thermal losses are a function of the glass temperature.
- Receiver condition doesn’t matter (vacuum, lost vacuum, hydrogen)
10 Cross-Sections

Max of Cross-section Maximums 107°C
Min of Cross-section Maximums 93°C
Average of Cross-section Maximums 98°C
Max – Min of Cross-section Maximum 14°C

Temperature Profiles of Cross-Sections

Sky Temperature
Receiver Glass Temperature
Mirror Glass Temperature
Top of Line
Bottom of Line
Solel UVAC2
(2 years old) with Vacuum

Visible Image of Receiver – Not Tracking

Infrared Image – Not Tracking (Glass Temp. 63°C-66°C)

Infrared Image – Tracking (Glass Temp. 68°C-71°C)
Visible Image of Receiver – Not Tracking

Infrared Image – Not Tracking (Glass Temp. 124°C-141°C)

Infrared Image – Tracking (Glass Temp. 138°C-267°C)

Getter dust is causing hot spots on the glass
Field Test Results
SEGS VI

Heat Transfer Fluid - Ambient Temperature (ºC)

Glass Envelop - Ambient Temp. (ºC)

- Black Chrome w/ Getters
- Cermet w/ Hydrogen Remover
- Cermet w/ Getters

Hydrogen
• IR camera provided a good approach for evaluating condition of a large number of receivers in the solar field.
  – A highly automated approach for imaging receiver and analyzing data developed
  – Good agreement between IR camera and thermocouple measurements
  – Able to take measurement while collectors tracking
  – Approximately 12,000 images of receivers taken (out of ~90,000 receivers)

• Results from testing:
  – Able to evaluate performance of various generations of original and replacement receivers.
  – Getter dust, dirt on glass, or fluorescent coating failure cause increased glass temperatures.
  – Results indicate a potential hydrogen build-up in receivers in solar field
• Improved automation of image acquisition
  – Integration of GPS for automated acquisition of images.
Infrared Camera Measurements through Glass
Absorber Surface Temperature Measurement Results
Non-Invasive Measurement of Gases in Trough Receiver

- Confined gases under low pressure emit characteristic spectra when a high voltage discharge is allowed to pass through the gases.
- The characteristic emission wavelengths provide the identity of the gas and the intensity of the emissions are proportional to the amount of gas.

Developed by:

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&

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NREL
- Hydrogen detected above ~300°C
- Corresponds to Increase in Glass Temperature & Increased Thermal Losses on Hot Receiver
Receiver Test Results

NREL test bed UVAC2
- Loss (W/m) = 0.41\*\Delta T + 1.11\*10^{-8}\*\Delta T^4

NREL test bed Schott PTR70
- Loss (W/m) = 0.39\*\Delta T + 1.21\*10^{-8}\*\Delta T^4

NREL test bed Receiver with H₂ in annulus

hydrogen starts coming out of getters
• Outdoor testing
  – 2-axis
  – Single collectors
  – Field Test Loops

• Indoor testing

• Rapid Field Observations
Mirror Washing

High Pressure Spray with Demineralized water
Deluge wash with Demineralized water
Thank You