Durability Testing of Parabolic Trough Receivers – Overheating, Thermal Cycling, Bellow Fatigue and Antireflex-Coating Abrasion

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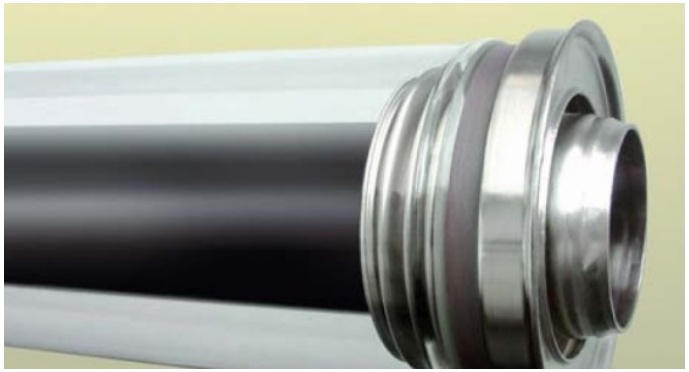
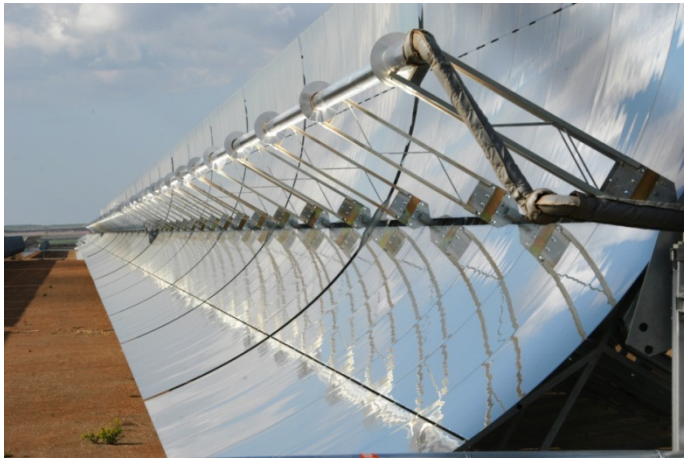
NECSO workshop

Eibar, 11.2.2016

Parabolic trough receiver





Performance parameters

- Optical efficiency $\eta_{opt,rec}(T)$
- Thermal loss power $P_{th,loss}(T)$

$$P_{coll} = \eta_{opt,rec} P_{in} - P_{th,loss}$$

Durability topics

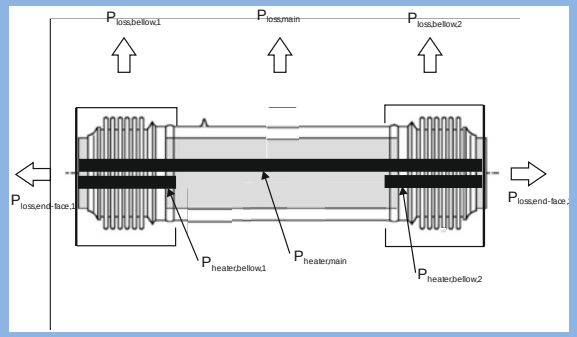
- ~25 years, ~10,000 day/night-cycles
- Absorber coating aging (300…400 °C)
- AR-coating aging (cleaning, sand storms, UV, aerosols, salt, acid rain, etc.)
- Vacuum quality
  - o Glas-to-metal seal and bellow tightness
  - o H2 diffusion

Lab testing of parabolic trough receivers at DLR

Receivers

Performance Tests

Heat loss

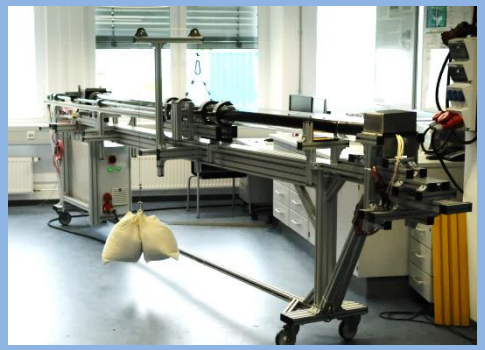


Optical efficiency

Accelerated Aging

Overheating

Bellow Fatigue



Small glass samples

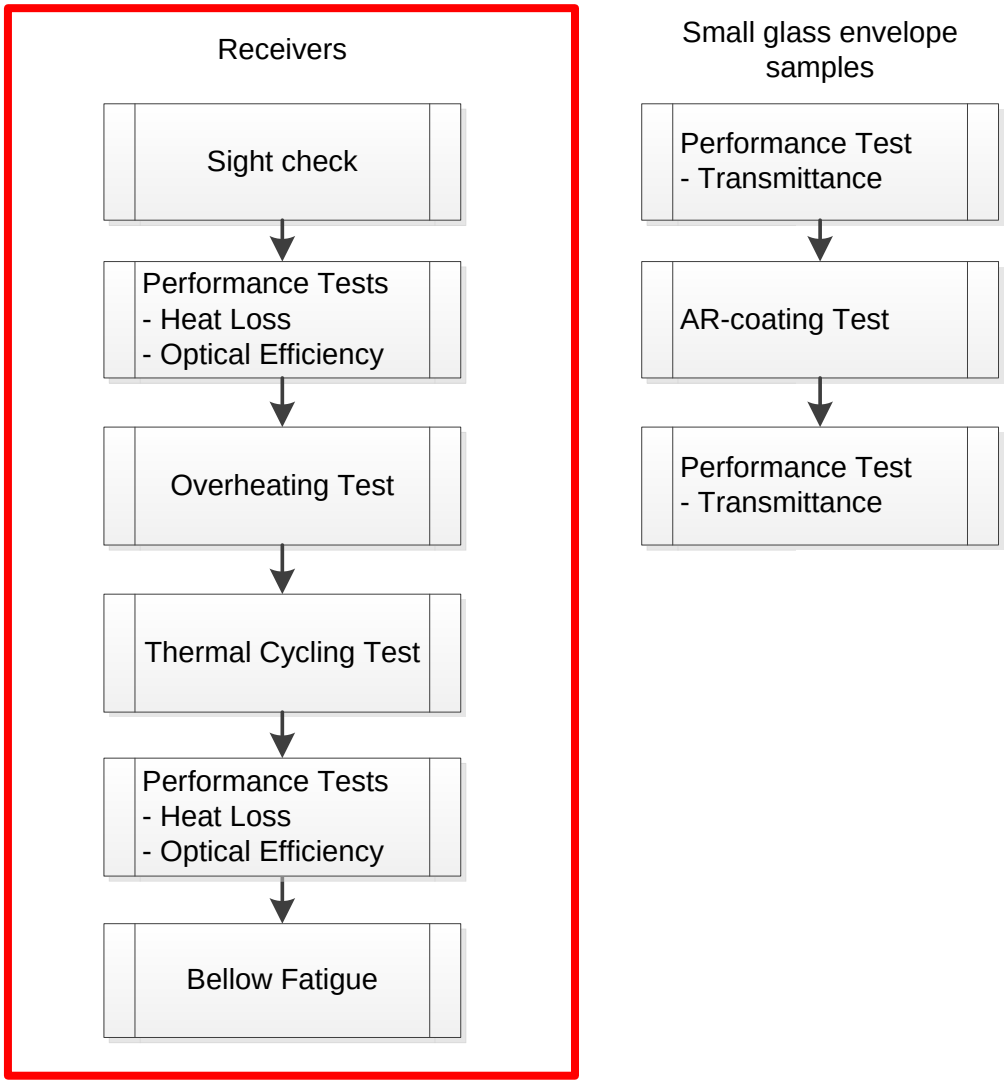
Performance Tests

Spectrophotometer

Accelerated Aging

Taber Linear Abraser and other

Testing scope

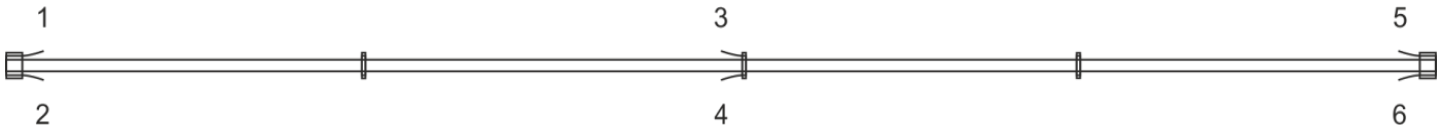


Overheating test bench

- Goal: Simulate aging of absorber coating due to high temperature (e.g. 400 °C for 25 years)
- Model: Arrhenius equation
- Method: Heating of receivers with internal heating elements significantly above operating temperature
- Necessary for Arrhenius:
  - activation energy E_n
  - validity

$$a_n = \exp\left[\frac{E_n}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_n}\right)\right]$$

Arrhenius equation



Overheating test bench

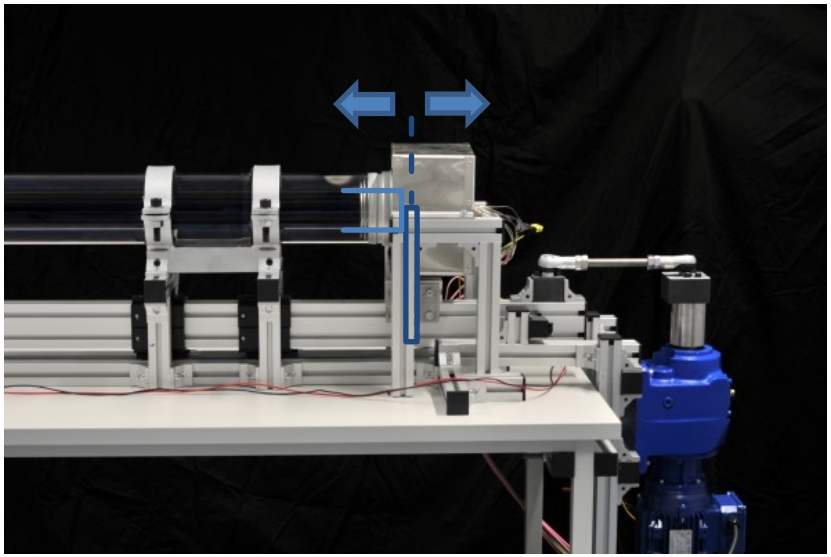
- 1st simplified comparative tests performed at 478 °C for 1000 h
- Heat up speed limit
  $\dot{T}$ < 5 K/min for T < 400 °C
- 1st heat-up
  $\dot{T}$ < 5 K/min for T < 400 °C
  24 h waiting time at 400 °C
  $\dot{T}$ < 0.05 K/min for T > 400 °C
- Testbench also used for thermal cycling at 200°C to 478°C for 100 cycles

$$a_n = \exp\left[\frac{E_n}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_n}\right)\right]$$

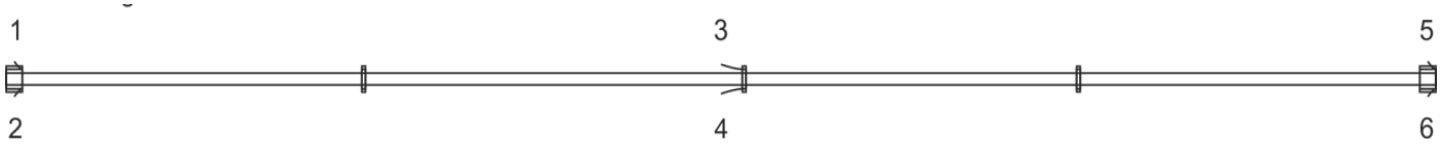
Arrhenius equation

Bellow fatigue test bench

First try

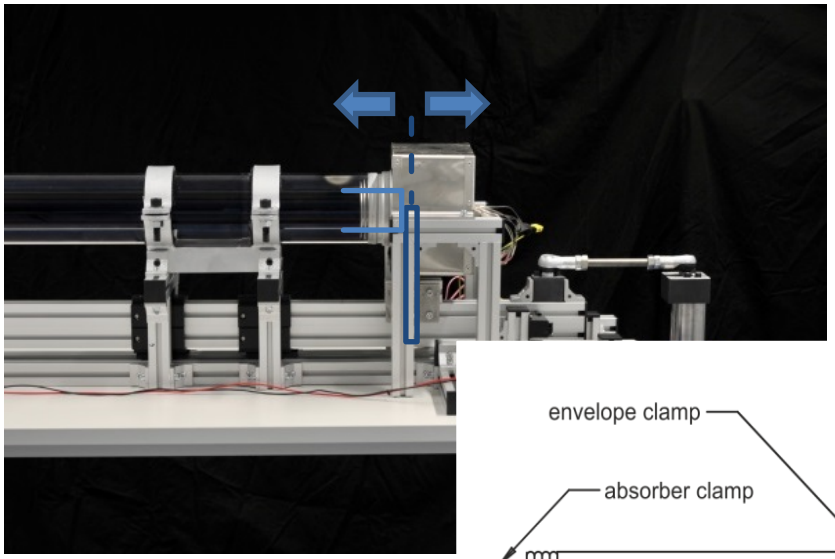


- Goal: Check bellow and glass-to-metal seal tightness after multiple compression/ expansion cycles
- Receiver heated to 200 °C
  → expansion half of maximum
- Absorber ends heated to 400 °C
  → maximum temperature
- Fix glass envelope
- Move absorber (0.3…1 Hz)
- Monitor heating power for detection of leakage
- Test: 20 000 cycles and wait 24 h
- Pass, if increase in HL < 30%

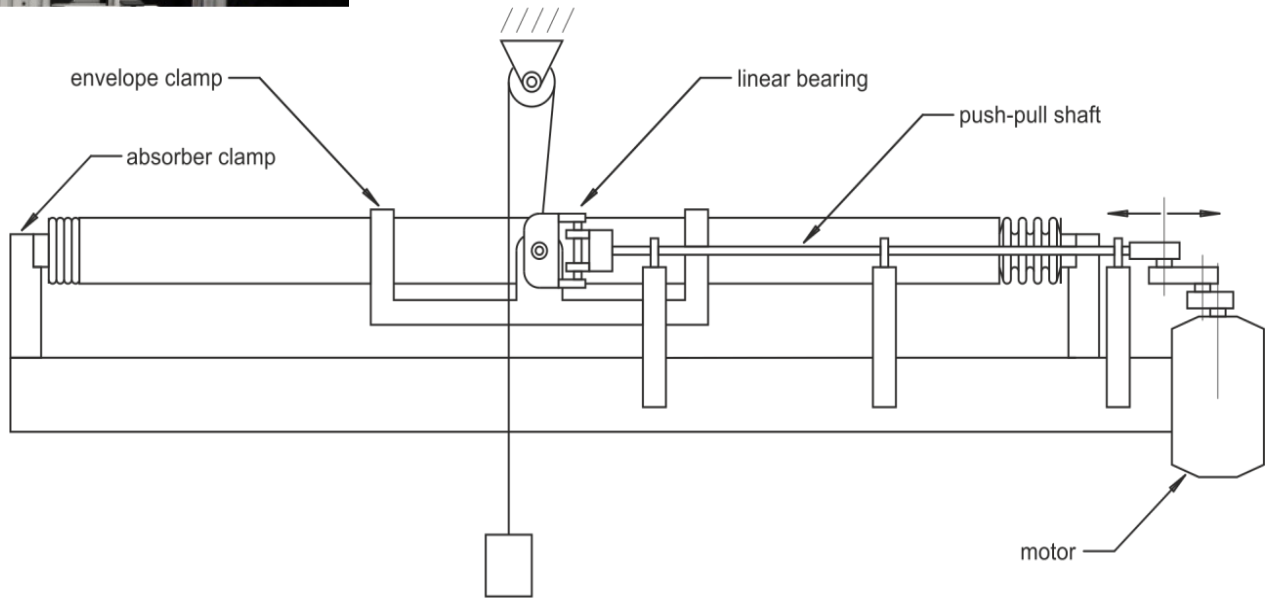


Bellow fatigue test bench

First try

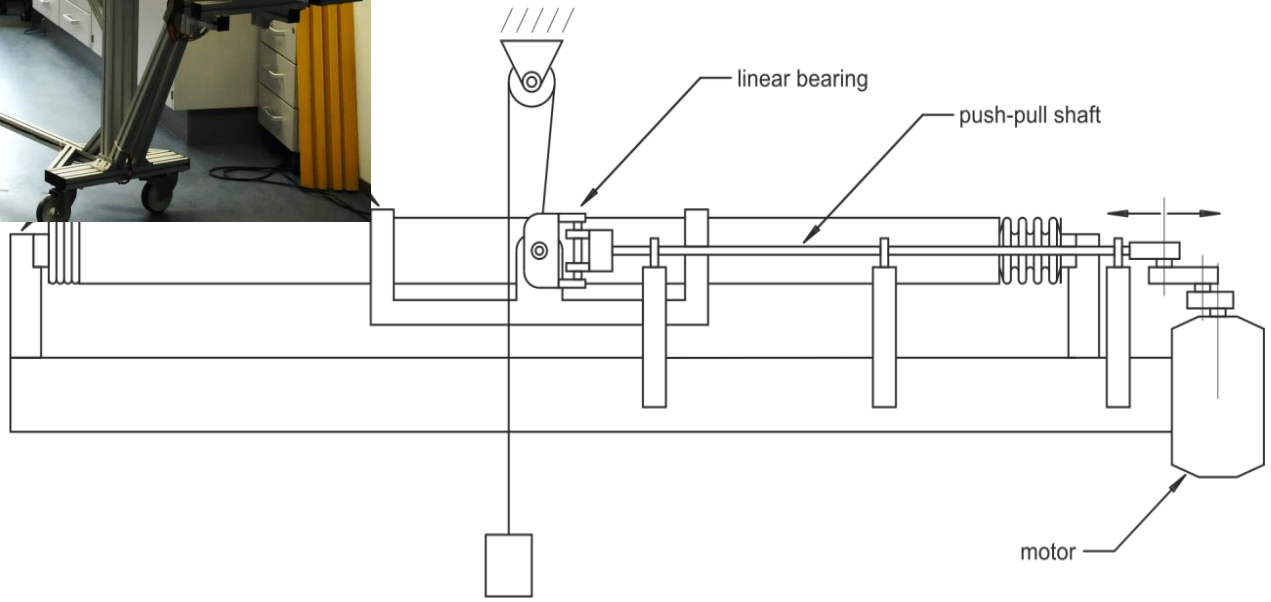


Second version

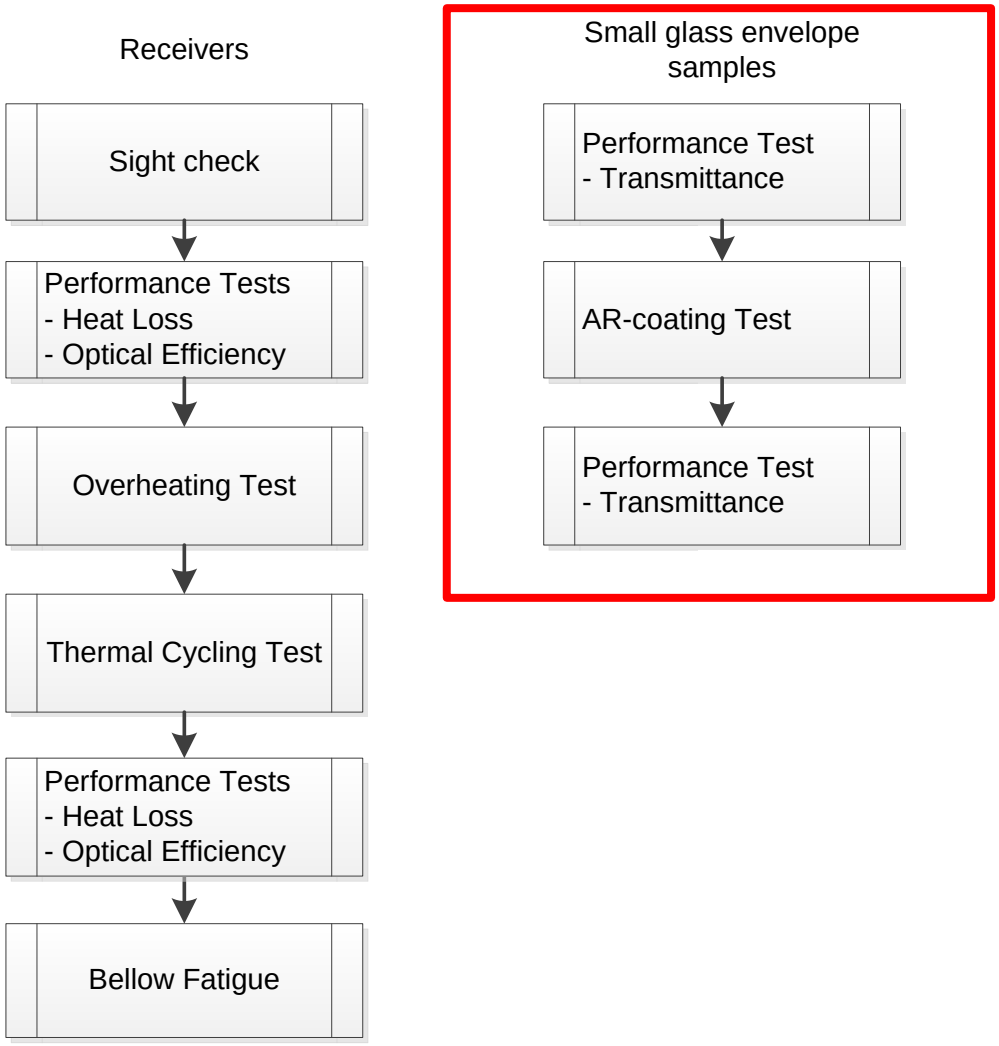


Bellow fatigue test bench

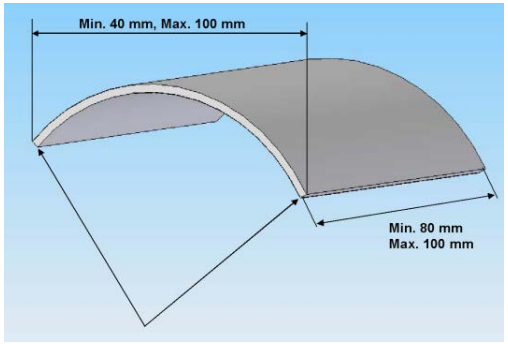
Real world version



Testing scope



Testing of anti-reflective coatings



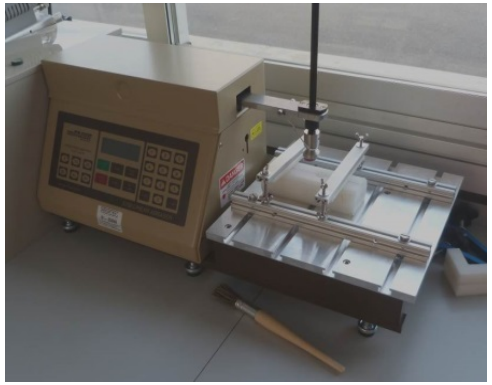
Possible AR-coating tests

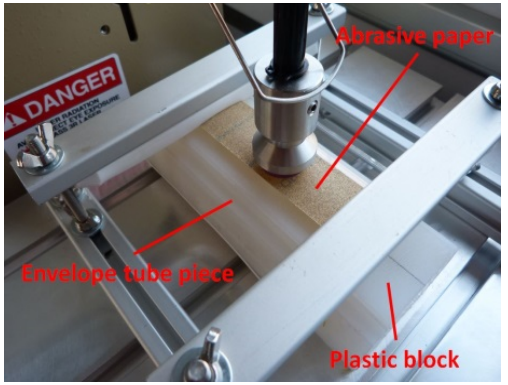
Test	Conditions	Duration	Measurement procedure
Condensation ISO 6270-2:2005	100% rel. H. 40±3°C	480h	Transmittance before and after the test
Taber Abrasion	MIL-E-12397 rubber, minimum weight 350±10g, stroke length 1.5“ frequency 7cycles/min test surface area 45 x 40 mm²	200 cycles	Transmittance measurement at 5,10,20,100,200 cycles. Stop before if coating completely removed
Sand erosion	Arizona test dust according to ISO 12103-1 A4 coarse with a particle diameter range of 1 - 180 µm, wind speed: 12 m/s Particle concentration 100 mg/m³	5 cycles Duration of 1 cycle: 10 min	Transmittance measurement after each cycle
UV and humidity ISO 16474-3	4h UV exposure at 60°C (~1 sun); 4h 100% RH at 50°C	2000 h	Transmittance before and after the test Or every 500 hours
Humidity freeze IEC62108 (Test10.8)	400 cycles from -40°C to 65°C; 40 cycles: 20h at 65°C and 85% RH, 4h -40°C	1500 h	Transmittance before and after the test Or every 500 hours

Under standardization by AENOR

Testing anti-reflective coating abrasion with the Taber Linear Abrasor

- Goal: Test AR-coating for abrasion stress
- Machine: Taber Linear Abrasor
- Transmittance measurement with spectrophotometer (Lambda 950/1050)
- Rubber preparation with abrasive paper
- Parameters
  - o rubber type
  - o rubber diameter
  - o cycle number
  - o speed
  - o weight



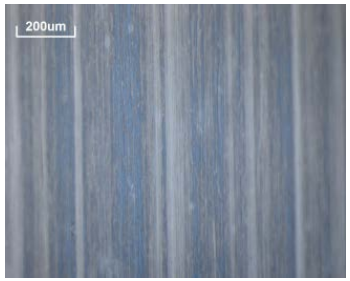


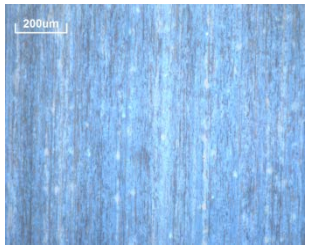
CS-10F ¾“

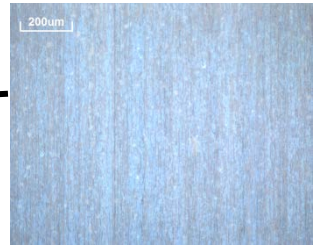
MIL 12397 ¼“
AENOR standard

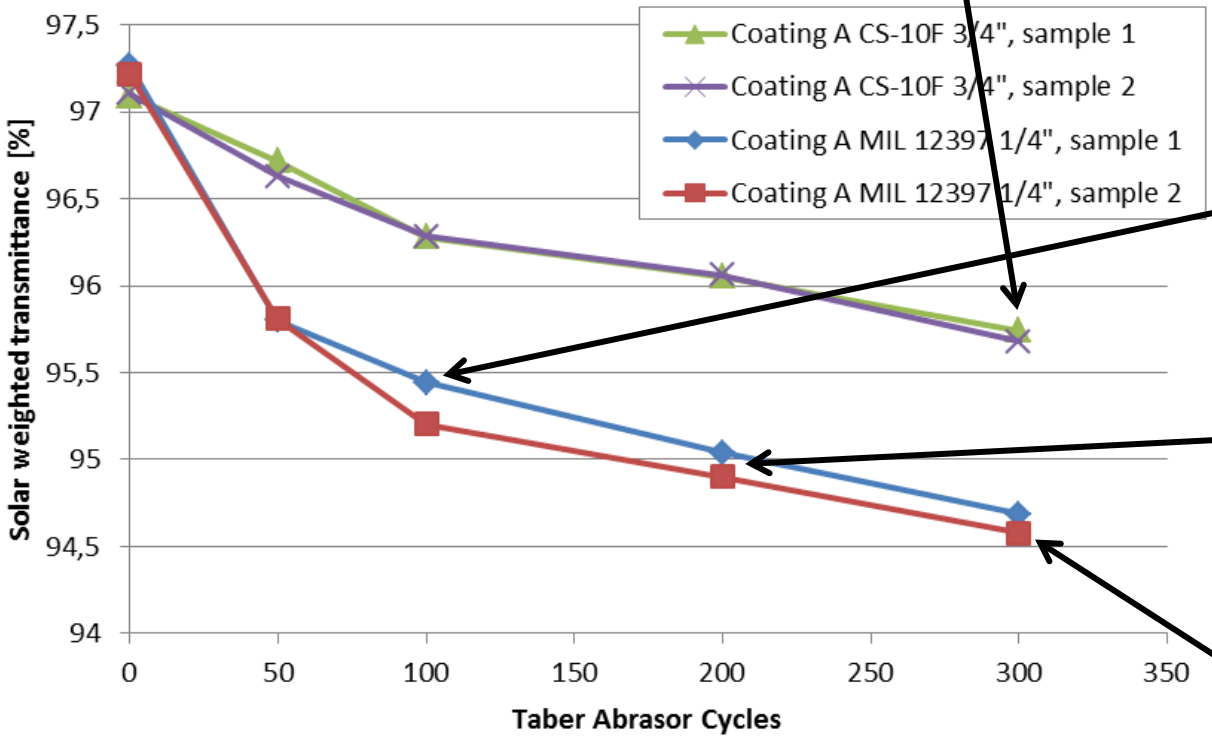
Exemplary results

initial





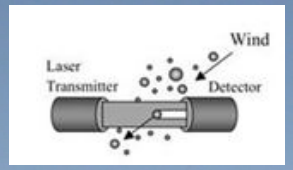




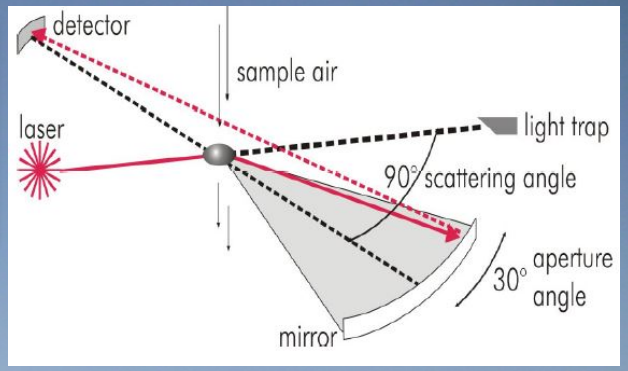
Sand erosion test: particle measurements at meteo station in Missour (Morocco)

Light barrier attached to mirror in 5 different heights

>40µm



Visibility sensor



Grimm particle sensor

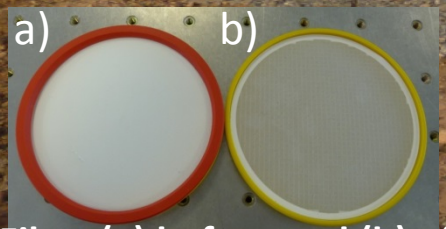
0.25-31µm

DustTrak

0.1-10µm

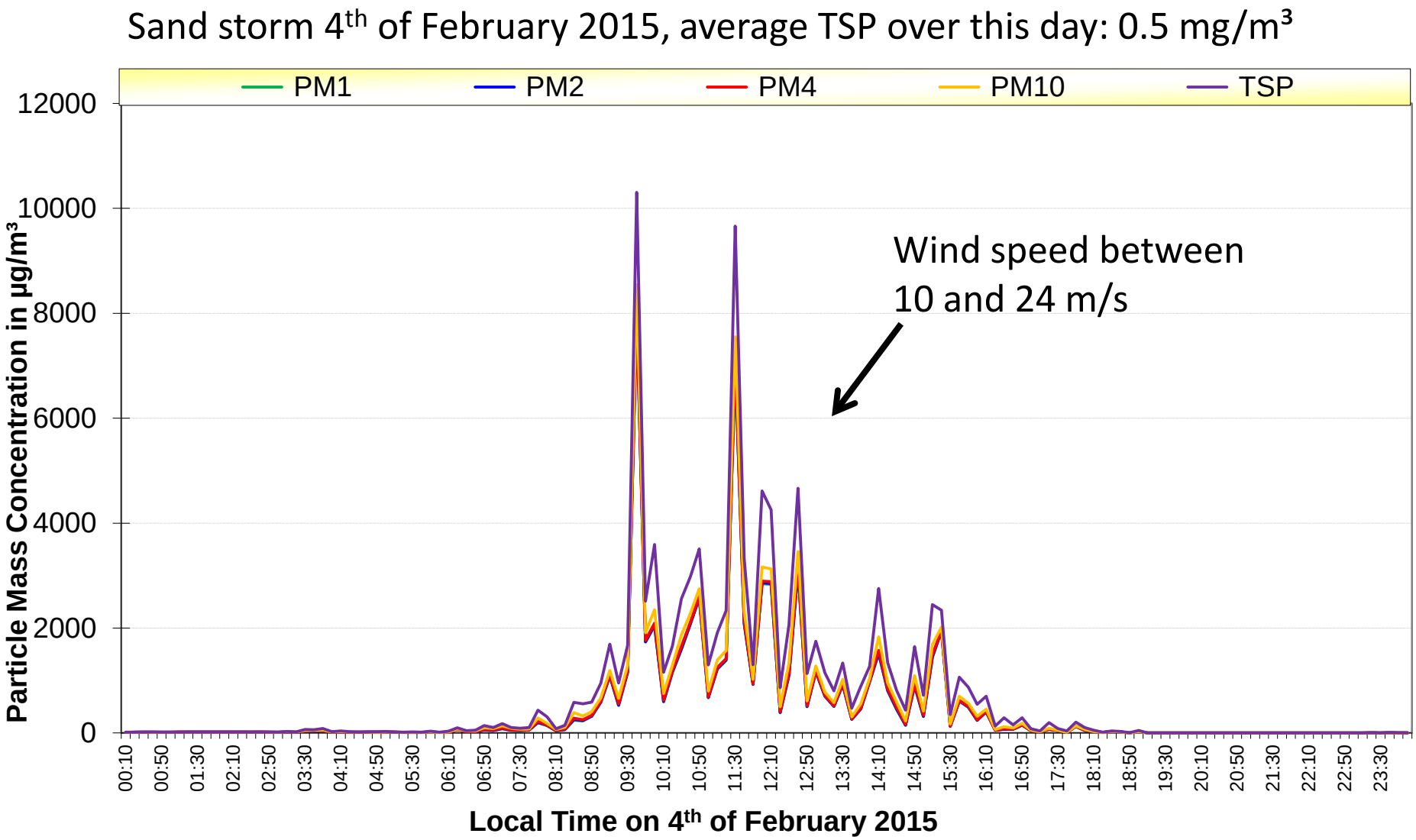
Filter particle sampler

TSP



Filter (a) before and (b) after 10 hour sampling at PSA

Sand erosion test: particle measurements at meteo station in Missour (Morocco)



Sandstorm data from literature review

Location	Maximum particle concentration [mg m^{-3}]	Mean particle diameter [µm]	Maximum wind velocity [m s^{-1}]	Duration [h]
Sahel/West Africa	13.7	3	5.3	3.5
Minquin/China	104.5	-	8.9	-
Zagora/Morocco	300	<200	11	-
Big Springs/Texas (USA)	1300	40	13	4
Mangyshlak/Kazahstan	40	10-250	11	-
Khartoum/Sudan	<40	10-50	9	6.5 max
Syracuse/Kansas (USA)	1327.4	50	11.5	-
Gobi/China	500	-	35 11 (avg)	26
Gansu/China	1016	-	34	2 days
Kuweit	9.6	-	11	4

Selected parameters to simulate sand storms

Arizona test dust according to ISO 12103-1 A4 coarse with a particle diameter range of 1 - 180 µm

Wind speed: 12 m/s

Particle concentration 100 mg/m³

Duration of 1 cycle: 10 min

5 cycles

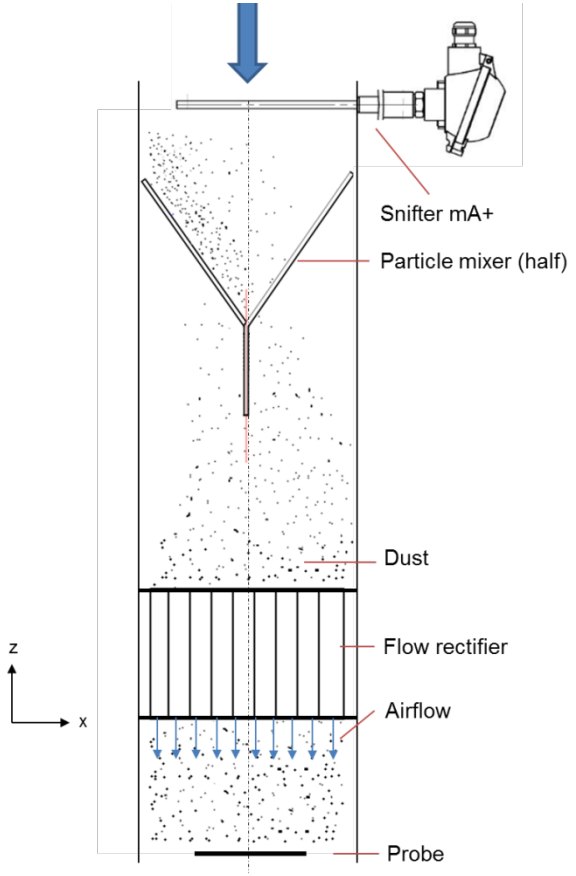
Measurement of transmittance after each cycle

Sand storm chamber at PSA, owned by CIEMAT

Development of an accelerated erosion test

Optimization of the particle flow in the sand erosion chamber by analysing glass mirrors

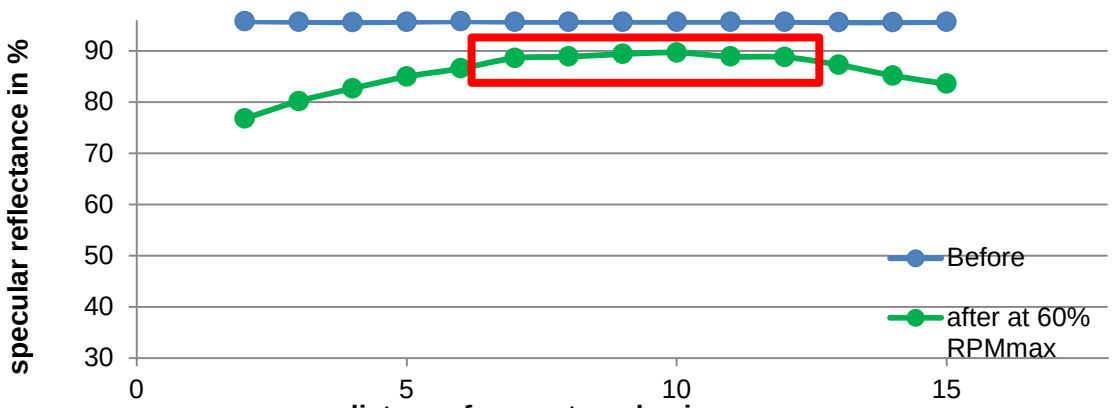
Schematic particle flow



Optimized state

(1) (2) (3)

Microscopic investigation sample outer edge, middle section and inner edge

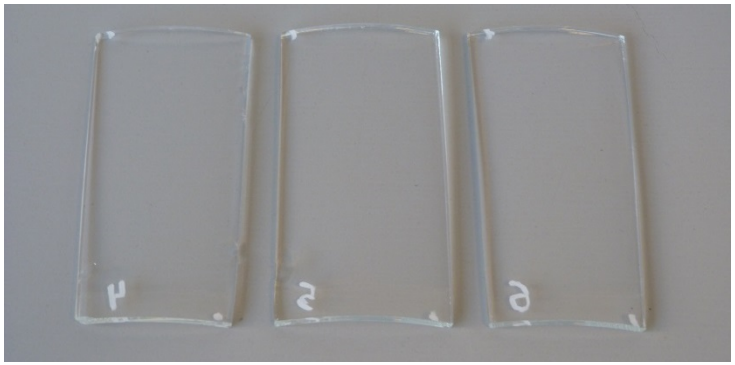


Specular reflectance of sample along cross section area

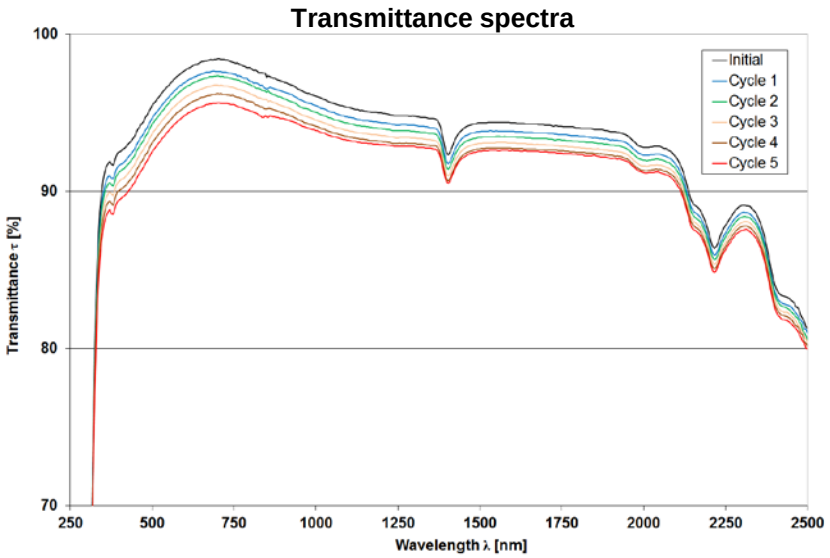
→ Homogeneous erosion on 6x6cm² samples is achieved!

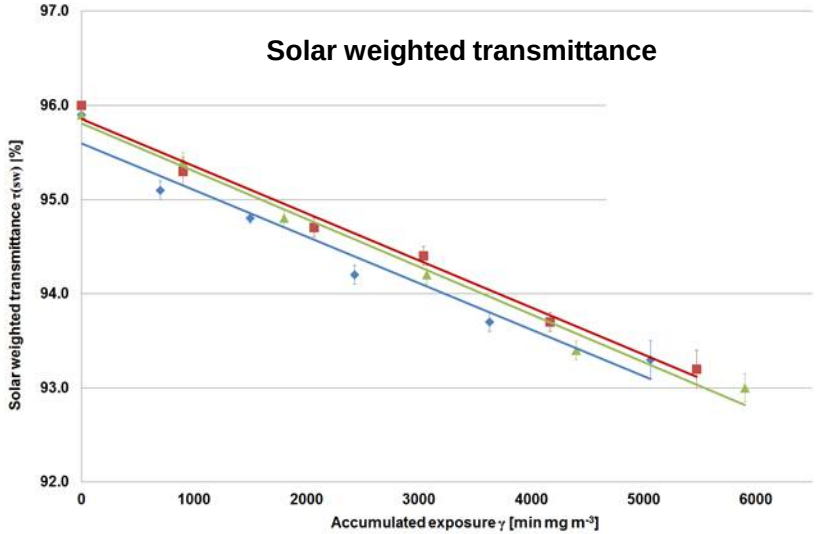
Sand erosion testing – exemplary results of AR-coated glass samples

Results presented by courtesy and permission of Royal Tech CSP Limited



AR coated glass envelope tubes





- Linear decrease of transmittance with testing time.
- Homogeneity and reproducibility verified.

Conclusion

- New tests for accelerated of parabolic trough receivers are available
  - o Overheating test with 478 °C for 1000 h
  - o Thermal cycling test with 200 °C to 478 °C for 100 cycles
  - o Bellow fatigue test bench
  - o Taber Linear Abrasor tests with Erasor MIL-12397
  - o Sand erosion test is available now

- First testing campaigns have been performed to compare different manufacturers

- More work is necessary on the transfer to the field

Next steps

- Acquire a vacuum furnace for the accelerated aging of small selective absorber samples and check Arrhenius equation
- Continue collecting field data on sand erosion to validate selected testing conditions
- Continue to work with AENOR to standardize the tests on national and international level

Thank you for your attention!

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