Steady State Criteria for Parabolic Trough Receiver Heat Loss Measurements

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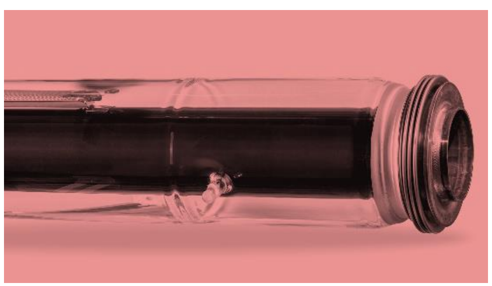


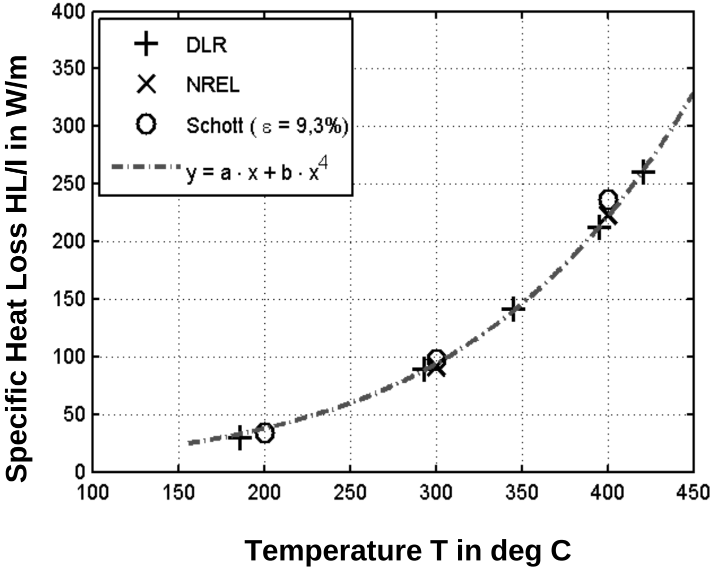
DLR

Parabolic Trough Receiver – Heat Loss

Performance parameters

- Optical efficiency $\eta_{opt,rec}(T)$
- Heat Loss $HL(T)$

$$P_{coll} = \eta_{opt,rec} \cdot P_{in} - HL(T)$$



Heat Loss Measurement – Common Method

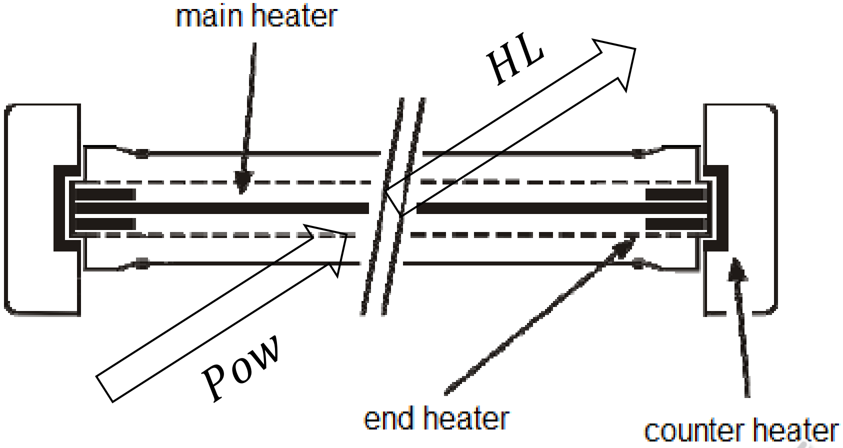
Principle

- In absorber tube
  - Electrical heater
  - Often homogenization tube
  - Thermocouples

Evaluation at Steady State

- Measurement of Pow and T
- Heating power = Heat loss power

$$Pow = HL$$



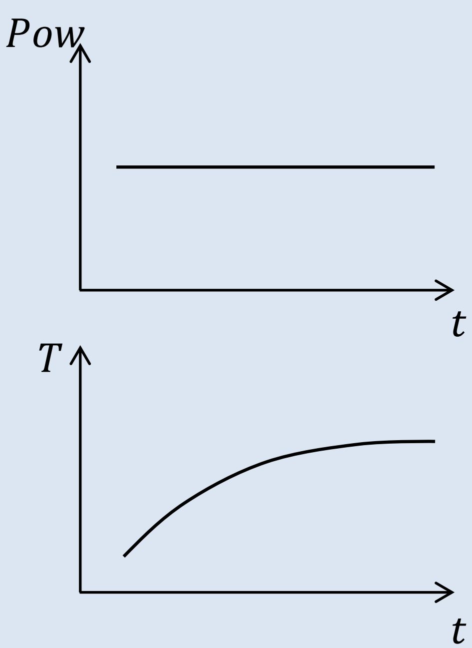
How to recognize a Steady State in practice?

- Noise
- Controller instability
- ↔ Insufficient waiting time

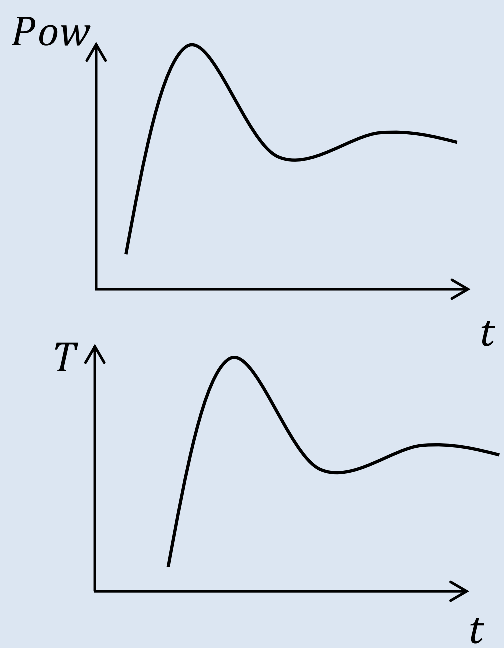
Heat Loss Measurement – Common Method

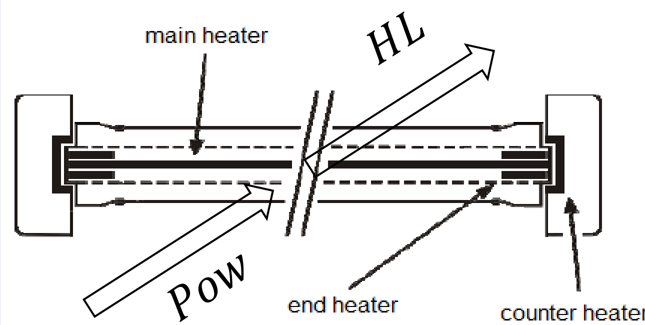
Heating strategies

Constant power



Closed-loop controller





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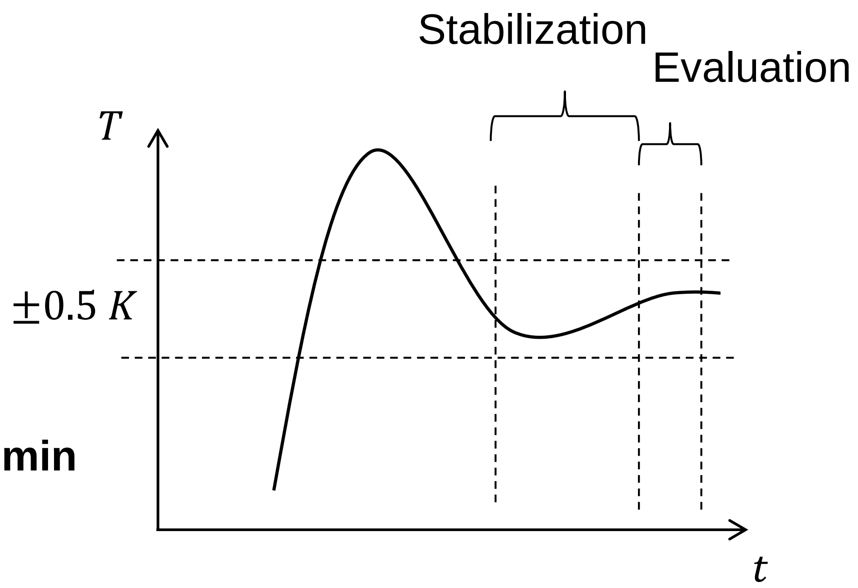
Criteria in Standard

- …
- $Pow \pm 1\%$
- $\boldsymbol{T \pm 0.5\ K}$
- Time period
    1. **Evaluation 15 min, stabilization 30 min**

    (2. Evaluation 15 min … 240 min)



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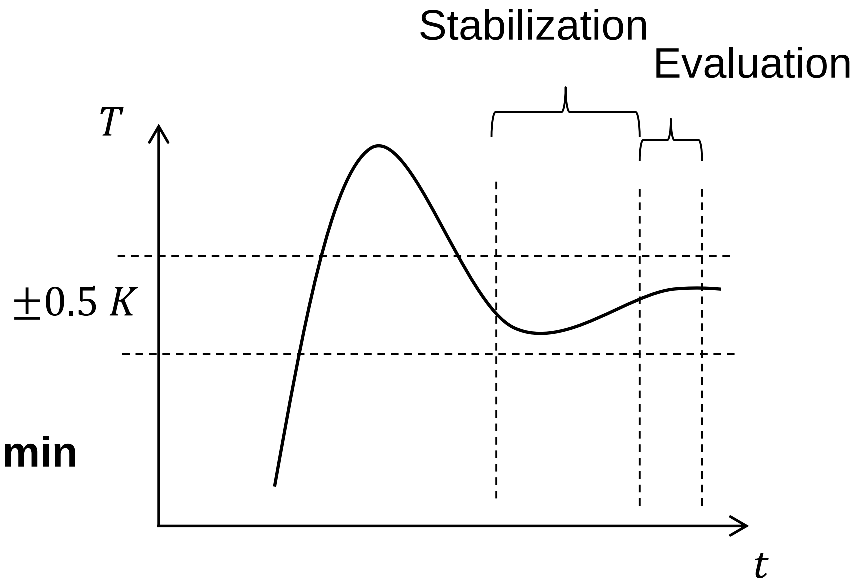

Criteria in Standard

- …
- $Pow \pm 1\%$
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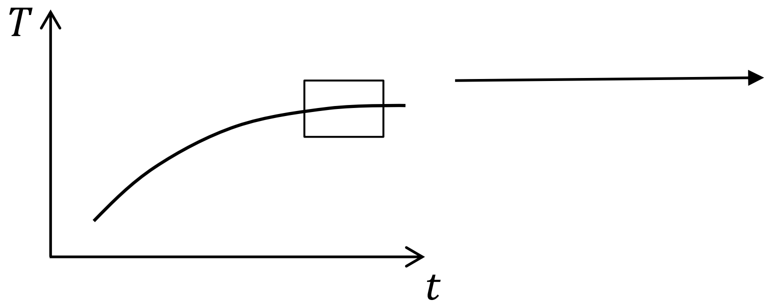
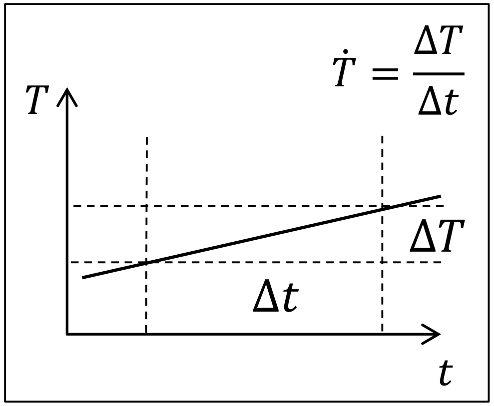
    1. **Evaluation 15 min, stabilization 30 min**
    (2. Evaluation 15 min … 240 min)

Low Noise System + Constant Heating + Large Time Constants

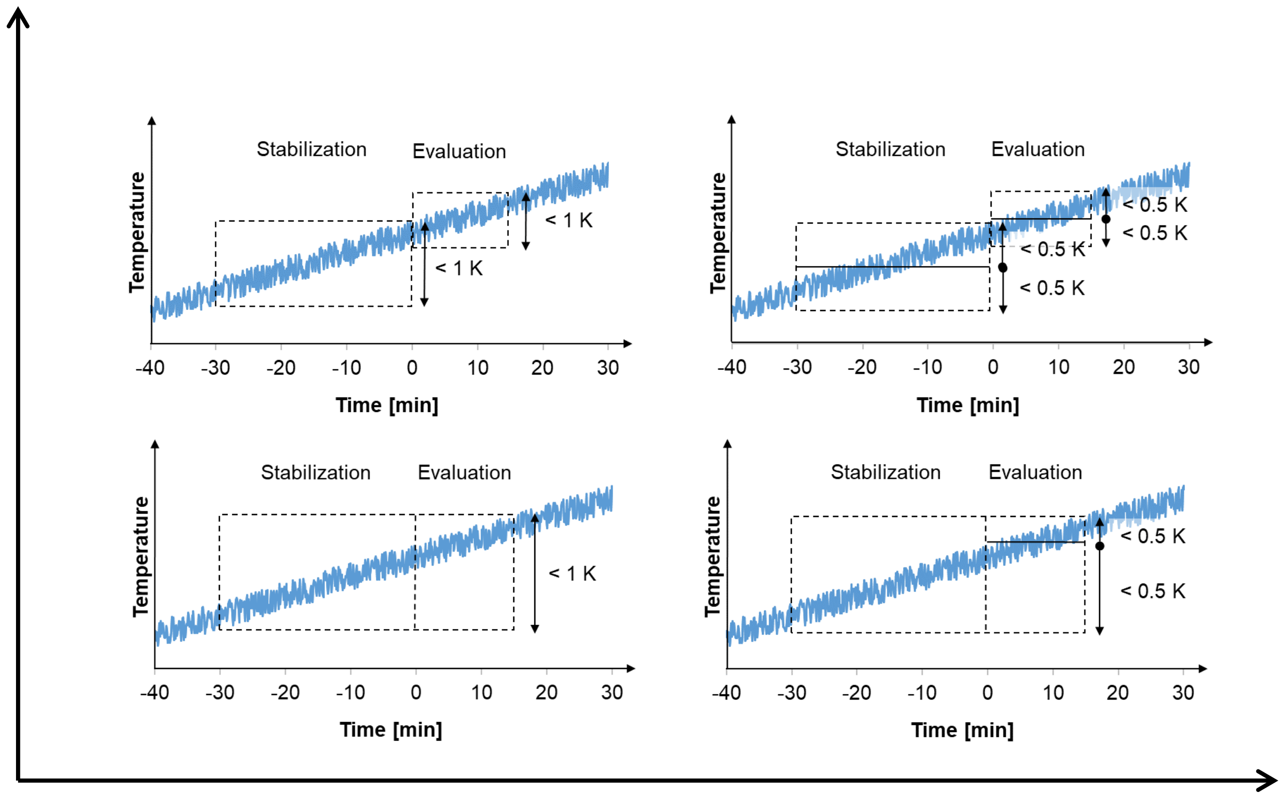




Interpretation of „± 0.5 K“

Borders for periods individually

Same borders for both periods



Max(T) – Min(T)

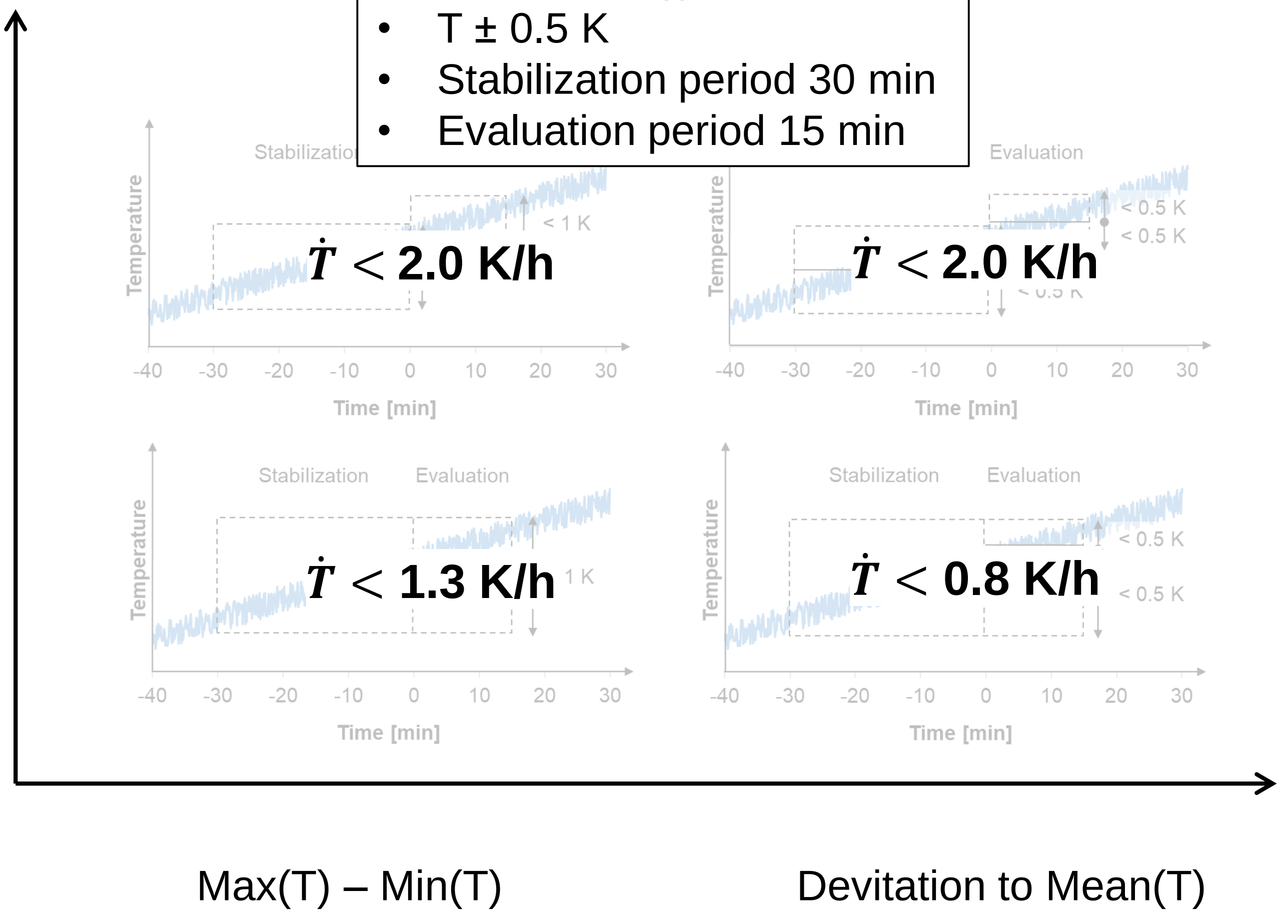
Devitation to Mean(T)

Interpretation of „± 0.5 K“

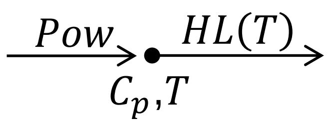
- No noise, T(t) linear
- T ± 0.5 K
- Stabilization period 30 min
- Evaluation period 15 min

Borders for periods individually

Same borders for both periods



Model for Constant Heating



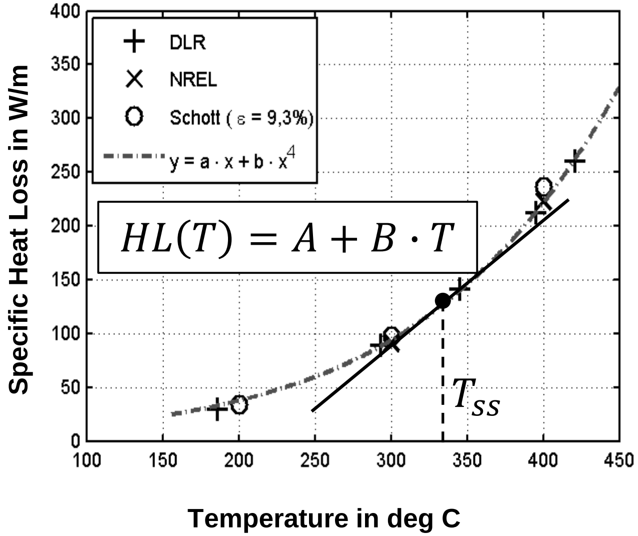
- Lumped Heat Model $\frac{dT}{dt} = \frac{1}{C_p}(Pow - HL(T))$
- Linearization of $HL(T)$ $HL(T) = A + B \cdot T$
- Steady state $HL(T_{ss}) = Pow = A + B \cdot T_{ss}$

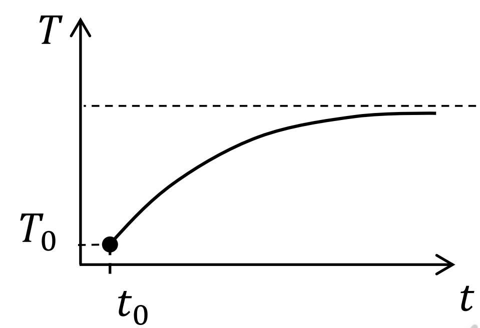
→ Differential equation $\boxed{\frac{dT(t)}{dt} = \frac{1}{\tau}(T_{ss} - T(t))}$

Time constant $\tau = C_p/B$

At t_0 $T(t_0) = T_0$

- Solution $\boxed{T(t) = T_{ss} + (T_0 - T_{ss}) \cdot e^{-\frac{(t-t_0)}{\tau}}}$
- Differentiation at $t = t_0$ $\boxed{\rightarrow \dot{T}_0 = (T_0 - T_{ss}) \cdot (-1/\tau)}$





Results – Example with high heat capacity

- Configuration: Receiver, heater with homogenization tube with C_p= 19640 J/K

					$\dot{T}_0$ = 2.0 K/h			$\dot{T}_0$ = 0.8 K/h	
T_{ss}	HL	B	τ		$T_0 - T_{ss}$	ΔHL		$T_0 - T_{ss}$	ΔHL
in °C	in W	in W/K	in min		in K	in -		in K	in -
100	28	0.8	400		**13.3**	38.5%		**5.3**	15.4%
200	141	1.7	188		**6.3**	7.7%		**2.5**	3.1%
300	362	3.4	96		**3.2**	3.0%		**1.3**	1.2%
400	807	7.0	47		**1.6**	1.4%		**0.6**	0.5%
550	2402	18.3	18		**0.6**	0.5%		**0.2**	0.2%

→ Criteria of standard allow large deviation from real Steady State at
- low temperature
- high heat capacity

→ Extreme case of 13.3 K deviation at 100 °C
→ 2.0 K/h for T ≥ 400 °C acceptable
→ 0.8 K/h for T ≥ 300 °C acceptable

Conclusion

- Steady state criteria in IEC-Standard ambiguous

- Model
  – Constant heating + Lumped heat + Linearization HL
  – Result: Steady State criteria insufficient at
    – low temperature
    – high heat capacity
  – Example: Meas. at 100 °C allows a deviation of 13 K

- Relevance: Criteria should be method-agnostic

- IEC-Standard
  - for T >= 300 °C ok with clarifications
  - for T < 300 °C modifications necessary

References

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[3] F. Burkholder and C. Kutscher, NREL-TR-550-45633 (2009)
[4] D. Lei et al., *Energy Conversion and Management*, (2013) **69** 107-115
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[6] IEC TS 62862-3-3:2020