The additional heat flux due to adhesion at a partially immersed rotating drum heat exchanger for latent heat storage

Jonas Tombrink, Dan Bauer

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Latent Heat Storage with the Rotating Drum Heat Exchanger

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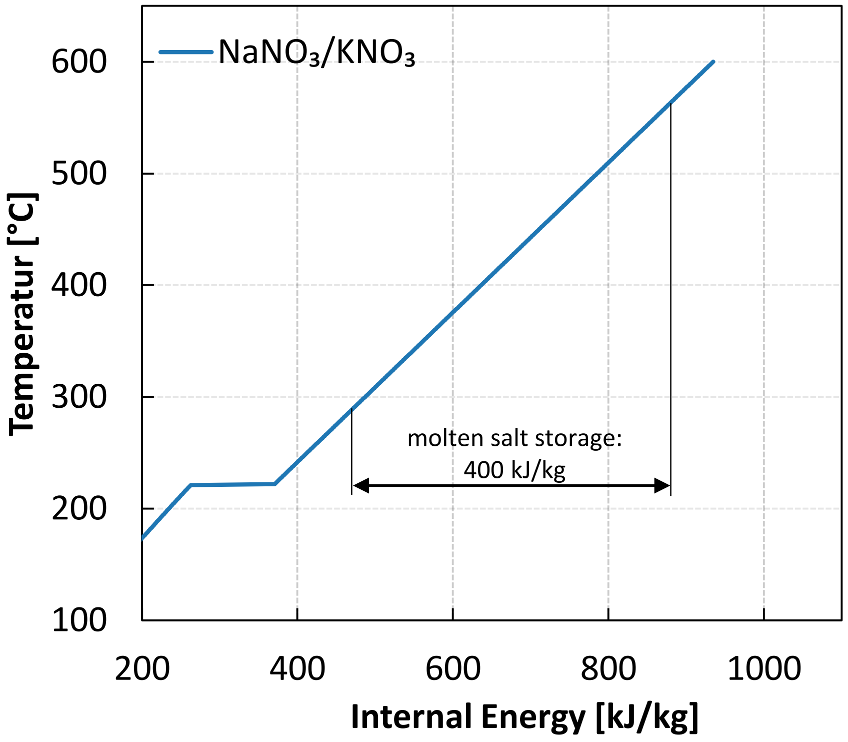

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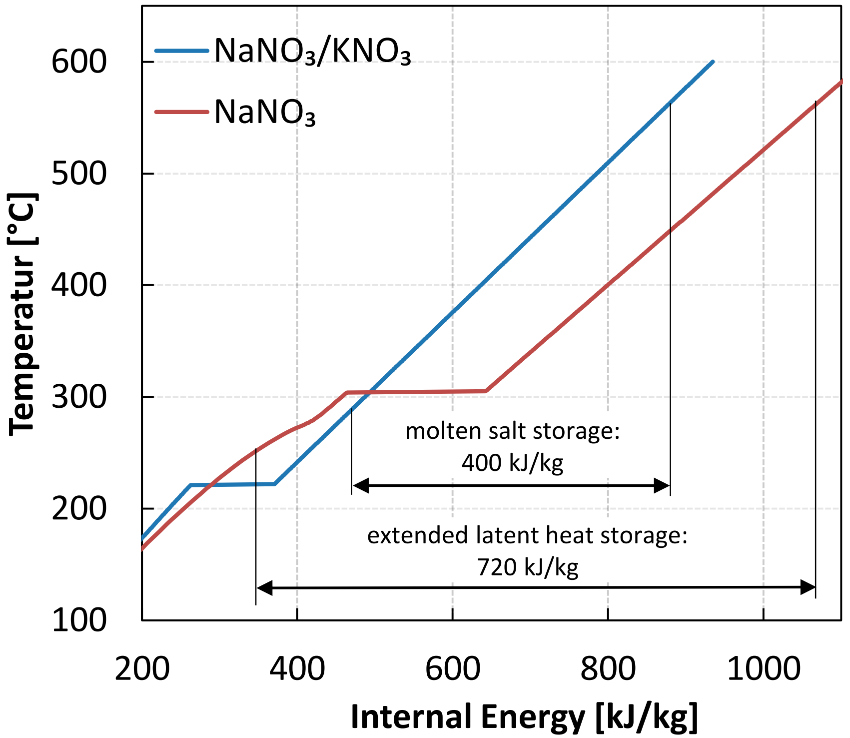

Latent Heat Storage with the Rotating Drum Heat Exchanger

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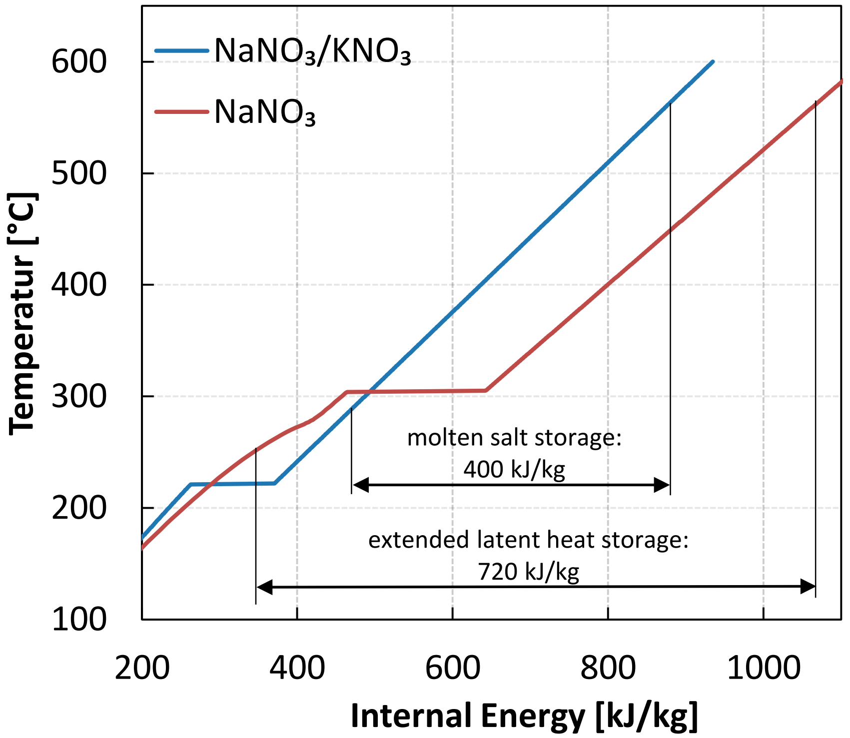
- Cost savings due to cheaper storage material and smaller storage tanks



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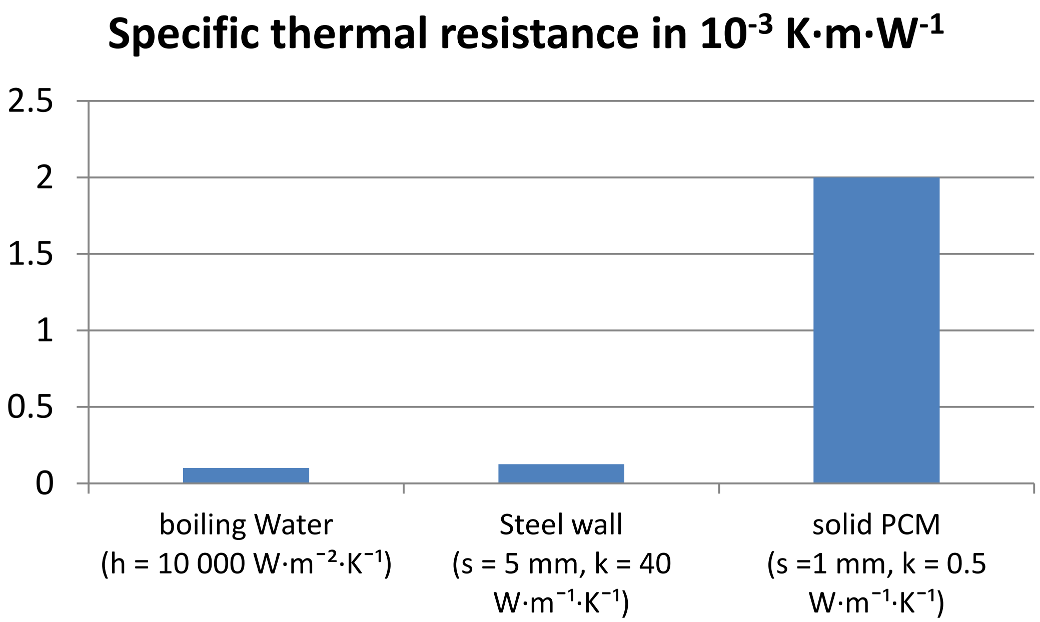

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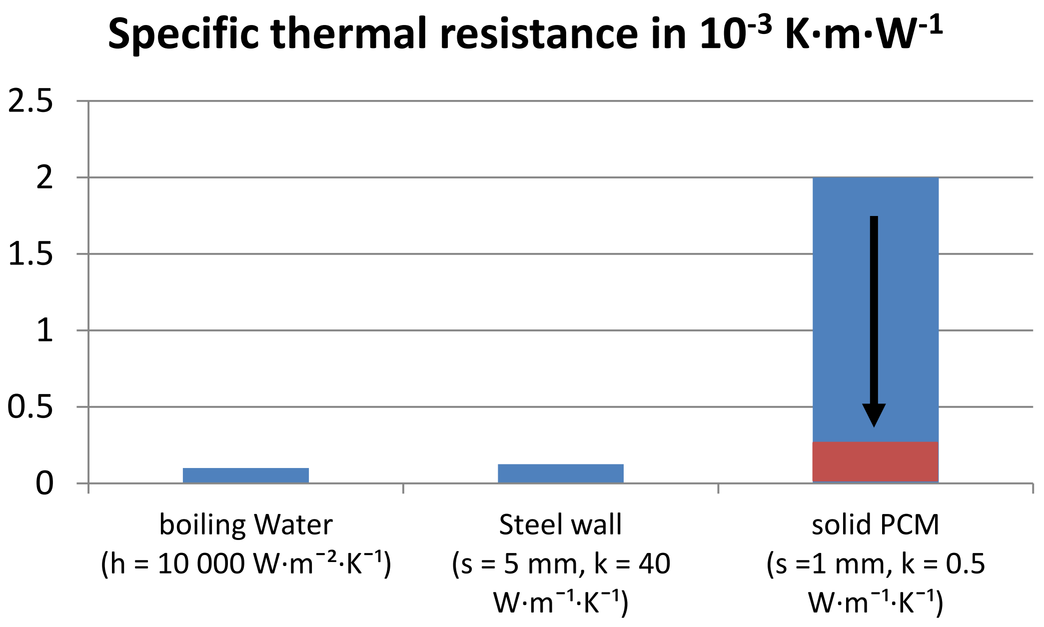
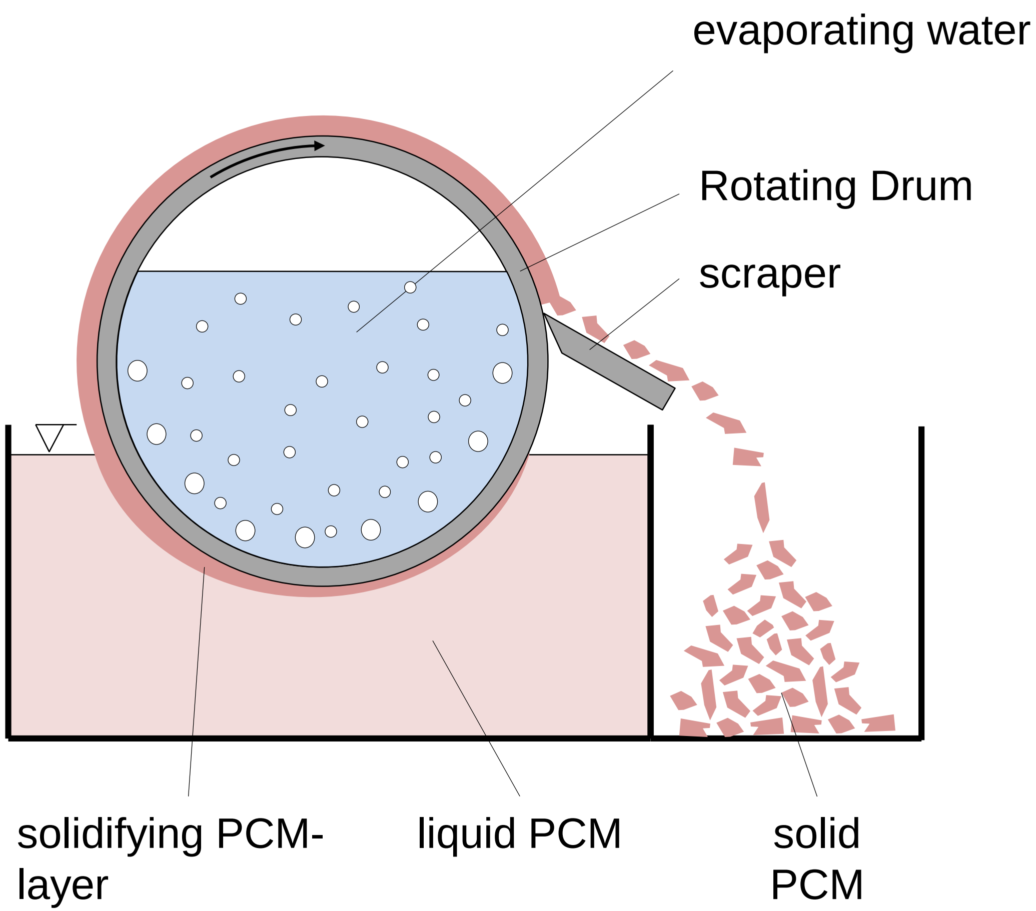
→ **Decreasing the solid PCM layer below 0.1 mm**



The Rotating Drum Heat Exchanger



Experimental Test Rig

- Lab scale test rig (d = 0.184 m, l = 0.4 m)
- Decanoic Acid (T_m = 31.5 °C) used as PCM
- Liquid water in an annular gap used as HTF
- Temperature of liquid PCM outside the drum $T_{l,PCM}$ and HTF inside the drum T_{HTF} can be controlled

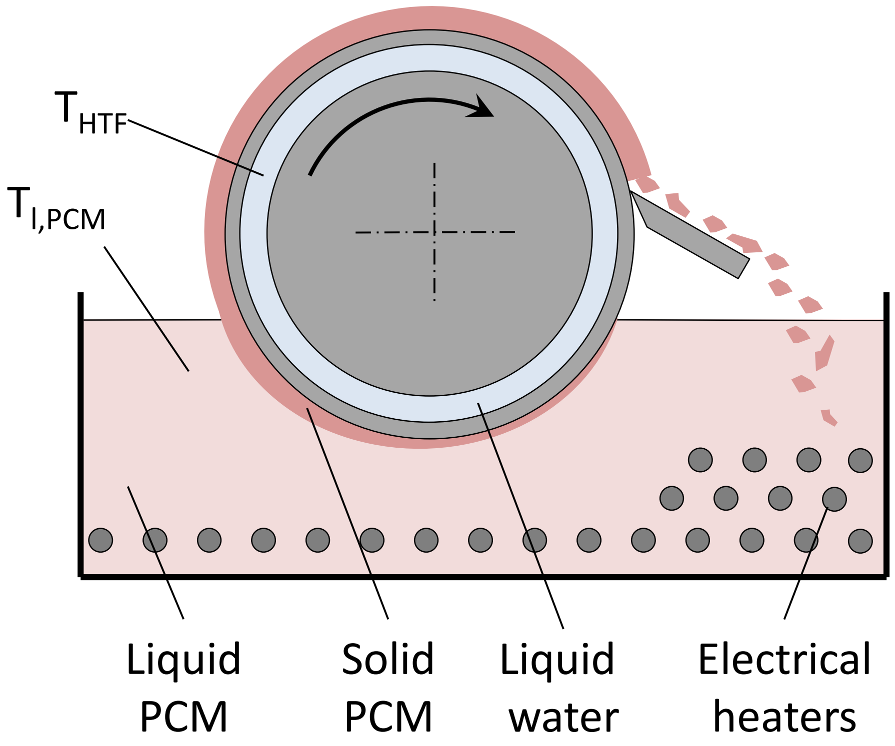
Within this präsentation:

T_{HTF} = 26.5 °C, $T_{m,PCM}$ = 31.5 °C, $T_{l,PCM}$ = 41.5 °C

Δ T total = 15 K

Δ T between T_{HTF} and $T_{m,PCM}$ = 5 K

Δ T between $T_{m,PCM}$ and $T_{l,PCM}$ = 10 K



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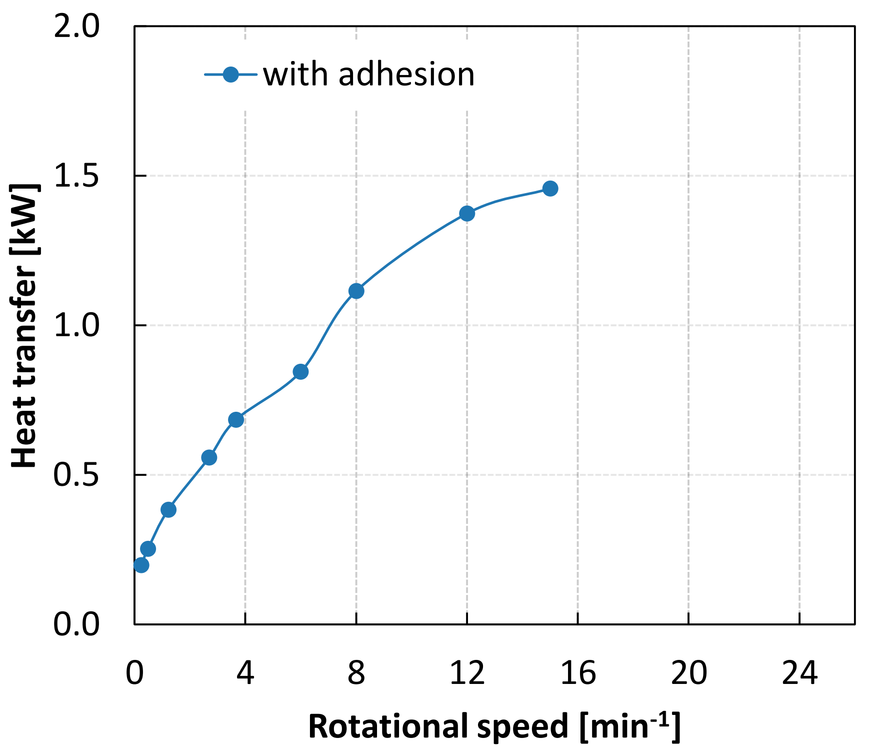
All experimental details and results can be found in:

J. Tombrink, H. Jockenhöfer, D. Bauer, Experimental investigation of a rotating drum heat exchanger for latent heat storage, Appl. Therm. Eng., 183 (2021) 116221. https://doi.org/10.1016/j.applthermaleng.2020.116221

Experimental Test Rig - Results

- Heat transfer increases with higher rotational speed
- At low rotational speeds, the heat transfer increases more when increasing the rotational speed compared to high rotational speeds
- Liquid PCM adheres to the drum when the surface is emerged from the tub



Measured heat transfer with a total Δ T of 15 K,
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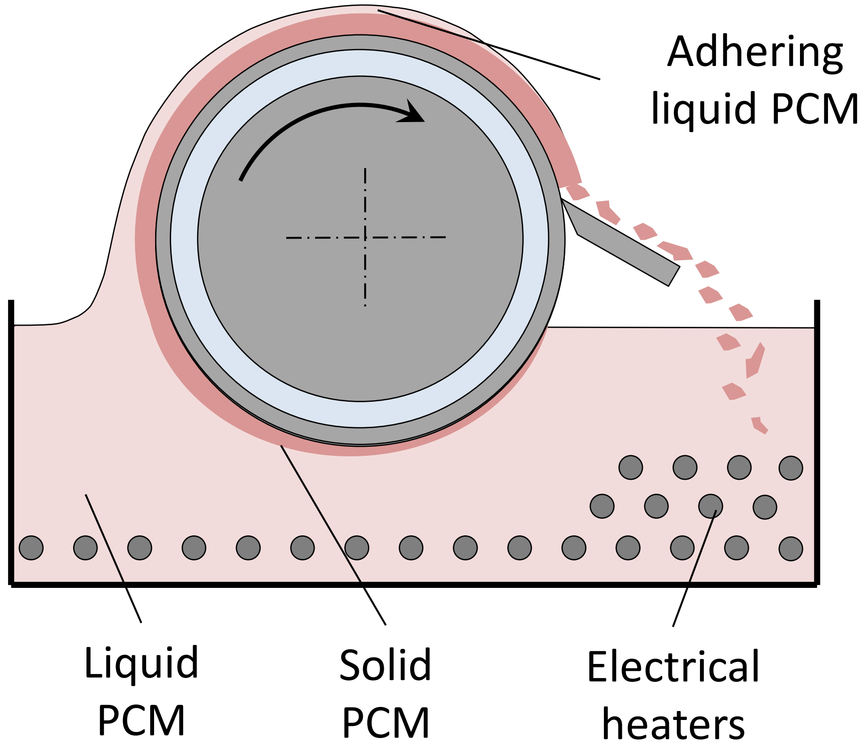

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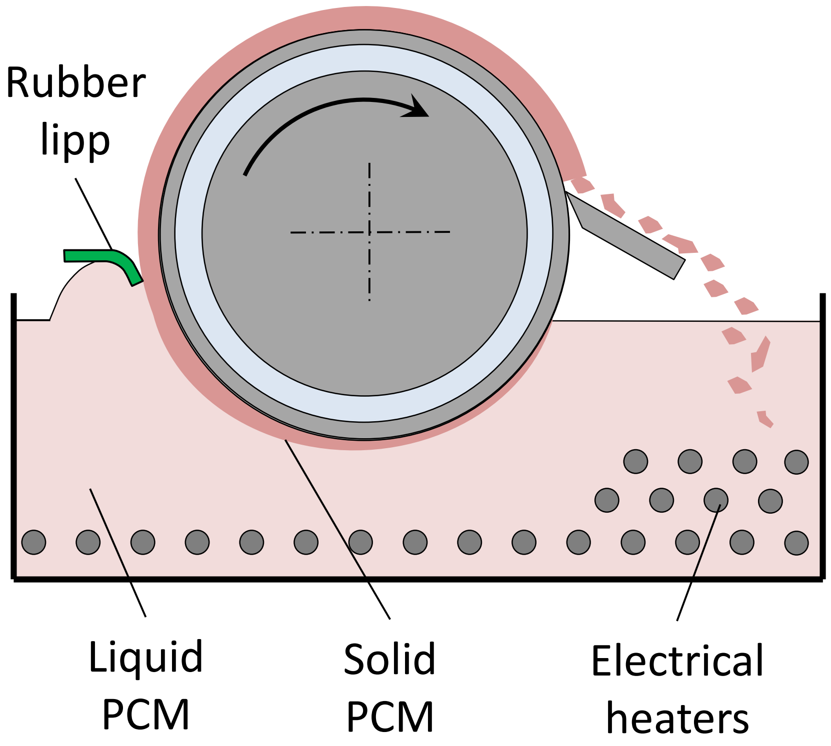

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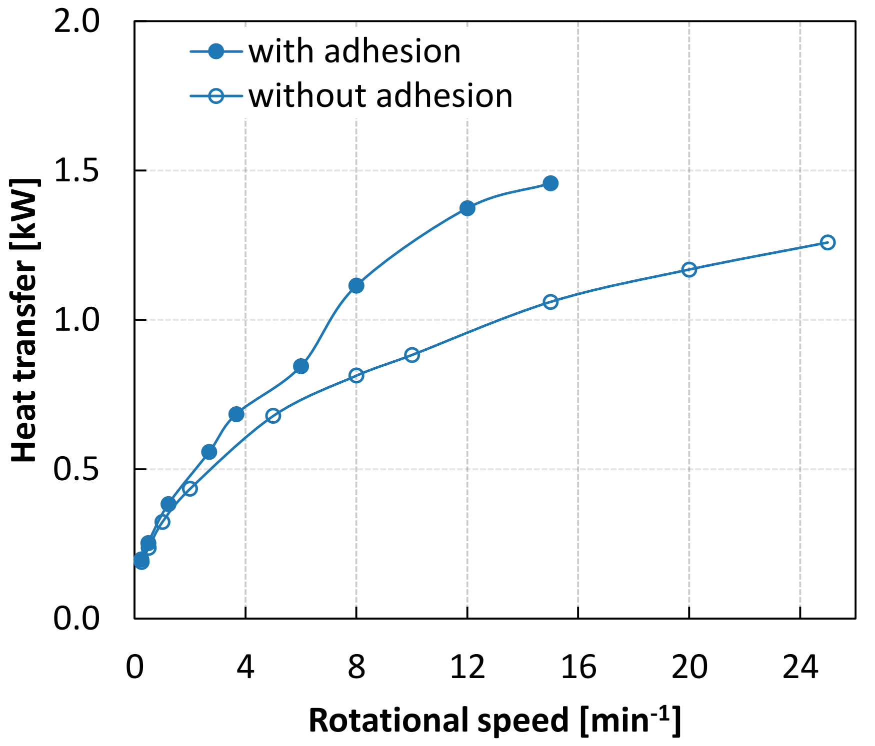
→Decrease of the heat transfer by 21 % on average



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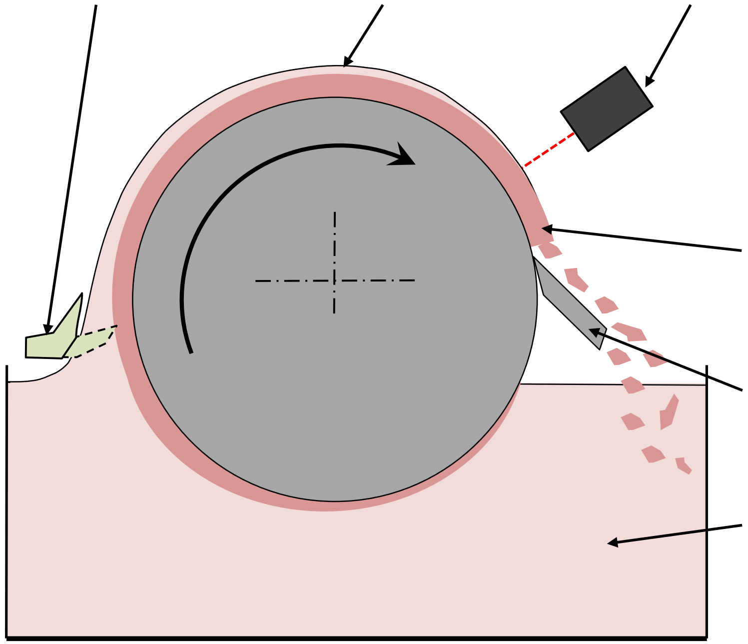
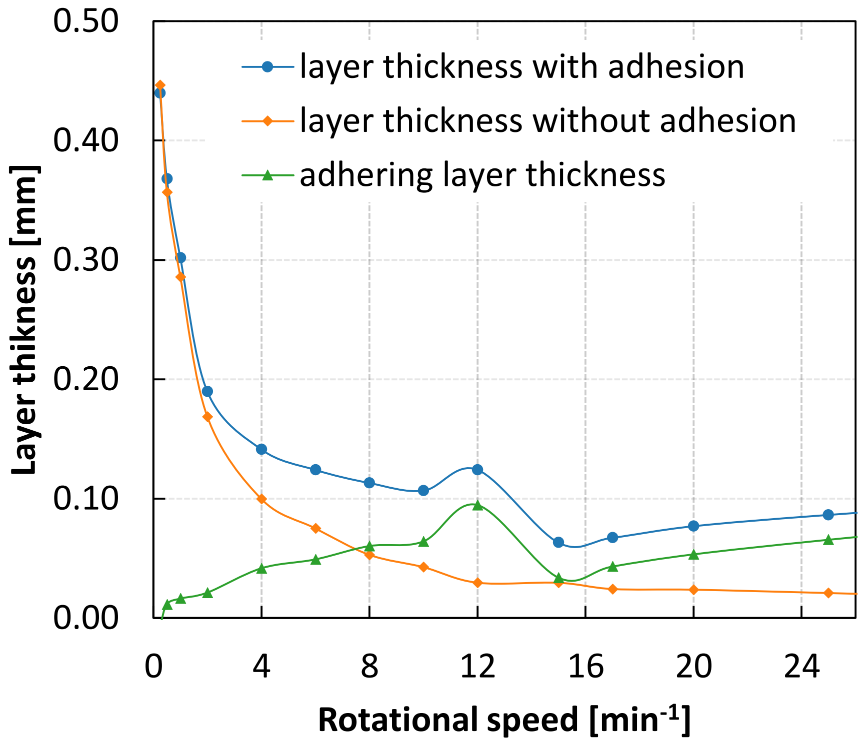
Experimental Test Rig – Measurement of the layer thickness





Measured layer thicknesses with a total ΔT of 15 K,
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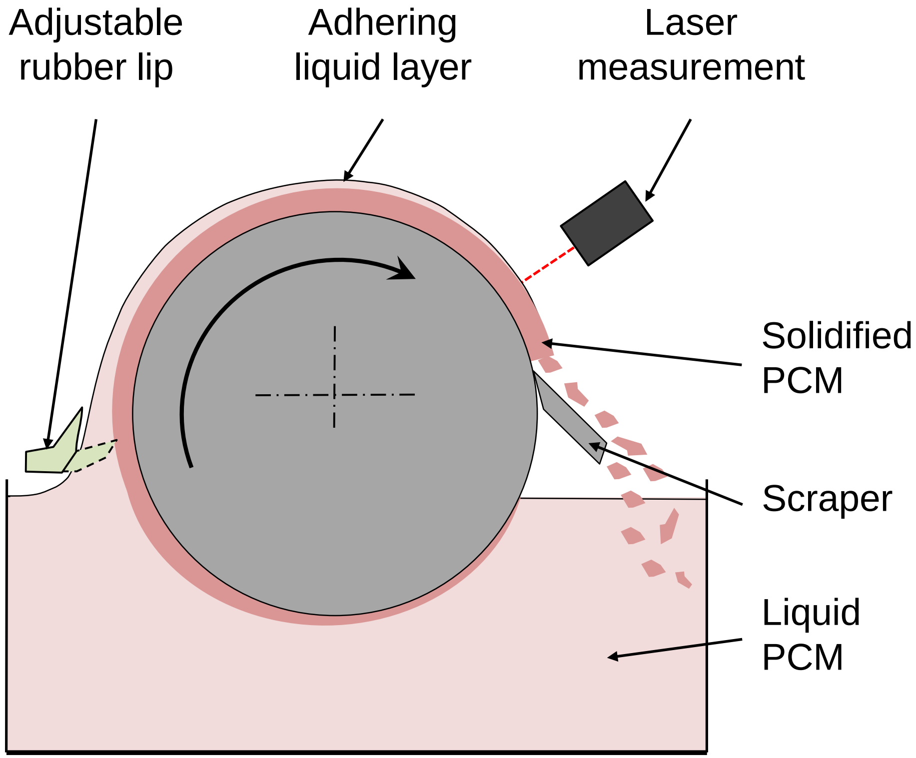

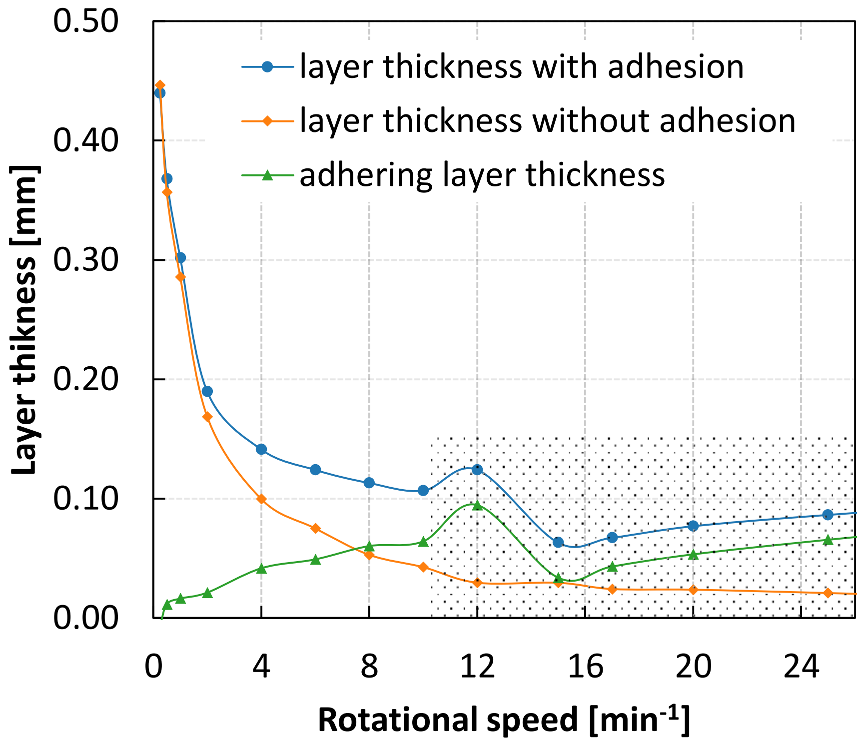

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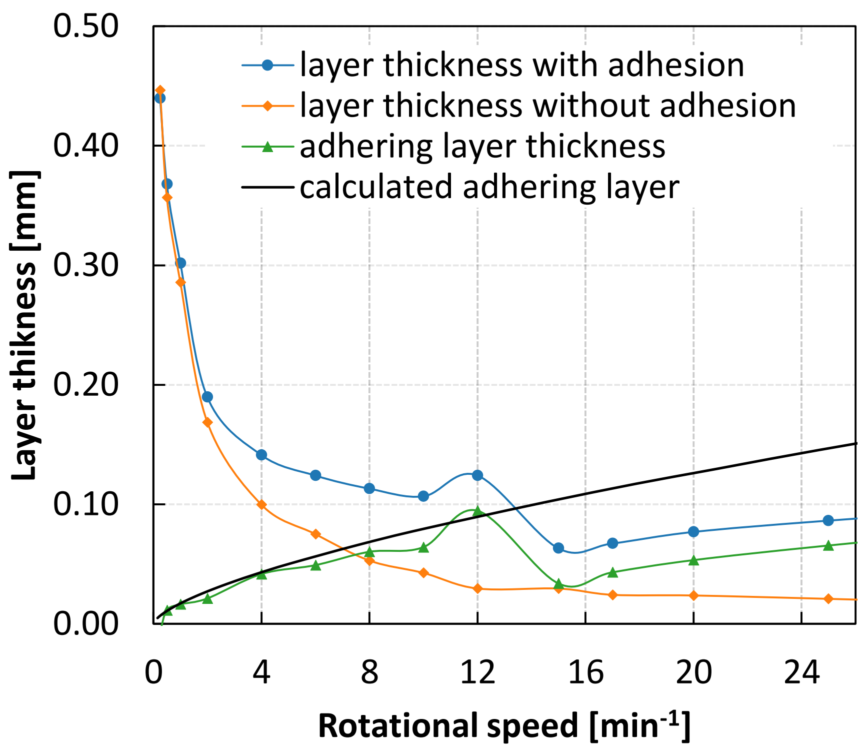
Experimental Test Rig – Measurement of the layer thickness

- Calculation of the adhering layer by a analytical approach of Gel‘perin et al.

$$\delta_{min} = 0{,}94 \cdot \left(\frac{2 \cdot \pi \cdot R \cdot n \cdot \mu}{\sigma}\right)^{\frac{1}{6}} \left(\frac{3 \cdot n \cdot R \cdot \mu}{2 \cdot \varrho_l \cdot g \left(1 - \frac{\alpha_0}{360}\right)}\right)^{\frac{1}{2}}$$

N.I. Gel'perin, G.A. Nosov, A.V. Makotkin, Determinating the thickness of liquid film holdup on a rotating drum surface, Chem. Pet. Eng., 11 (1975) 230-233.
https://doi.org/10.1007/BF01146631



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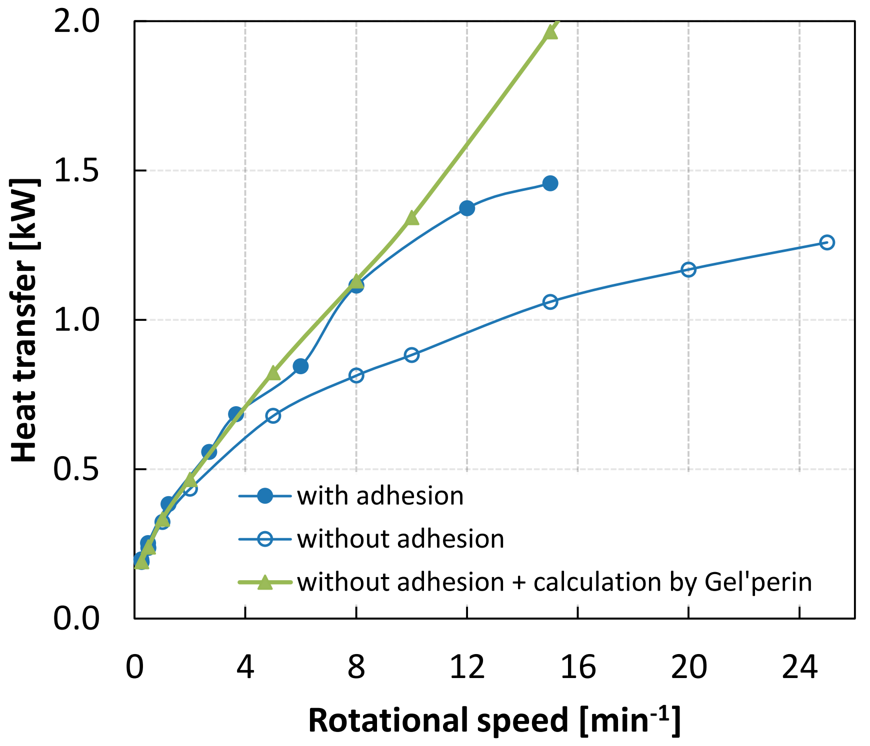
Additional heat flux from adhering layer

Additional heat flux from adhering layer:

$$\dot{Q}_{adh} = \dot{m} \cdot \Delta h = 2 \cdot \pi \cdot n \cdot R \cdot L \cdot \boldsymbol{\delta_{min}} \cdot \varrho_s \cdot \Delta h$$



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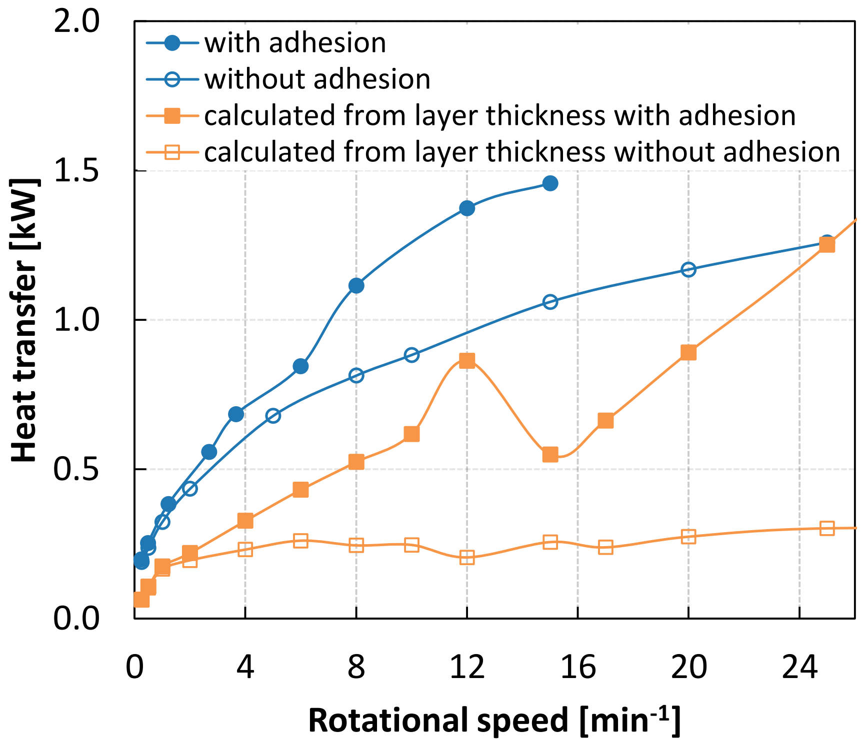
Heat flux calculated from layer thickness

Heat flux calculated from layer thickness:

$$\dot{Q} = \dot{m} \cdot \Delta h = 2 \cdot \pi \cdot n \cdot R \cdot L \cdot \delta \cdot \varrho_s \cdot \Delta h$$

- Calculated heat transfer from the layer thickness underestimates the experimentally measured heat transfer
- Underestimation:
  - in case of no adhesion: 52 %
  - In case of adhesion: 63 %
- Heat transfer composes of thermal conduction and phase change enthalpy



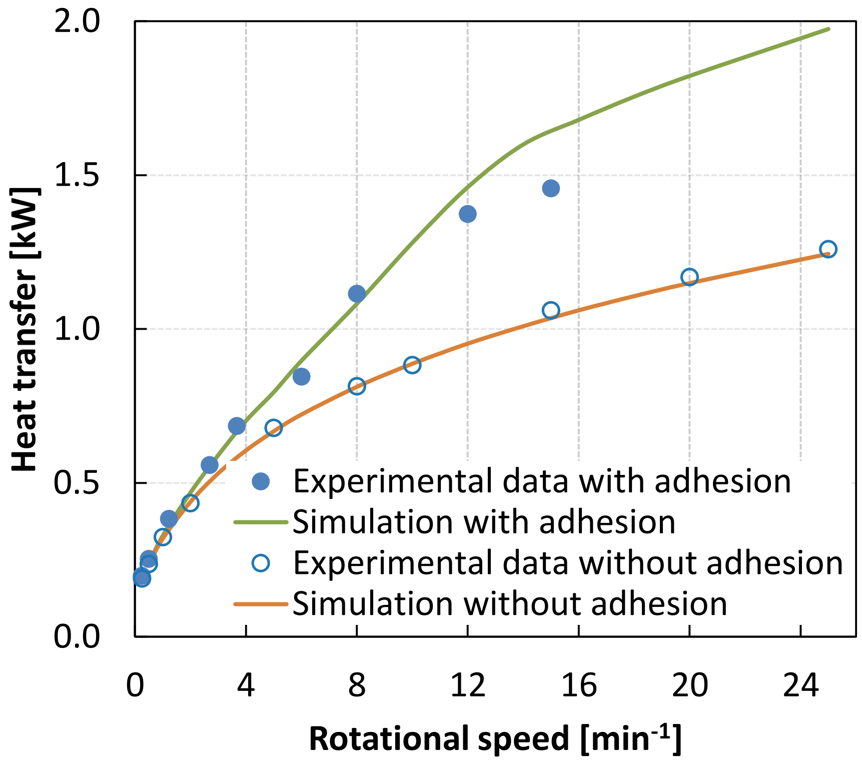
Measured heat transfer with a total Δ T of 15 K, ΔT between $T_{l,PCM}$ and $T_{m,PCM}$ = 10 K, ΔT between T_{HTF} and $T_{m,PCM}$ = 5 K

Detailed transient numerical simulation of the heat transfer

- Transient 1D time-varying finite difference scheme
- Adhesion according to Gel'perin
- Surface specific heat transfer coefficient at the solidification surface based on a correlation of Tsou et al.
- Reproduction of the experimentally measured heat transfer with an accuracy of 8 % on average

Simulation details can be found in:

J. Tombrink, D. Bauer, Simulation of a rotating drum heat exchanger for latent heat storage using a quasistationary analytical approach and a numerical transient finite difference scheme, Appl Therm Eng, 194 (2021) 117029. https://doi.org/10.1016/j.applthermaleng.2021.117029



Measured and simulated heat transfer with a total ΔT of 15 K,
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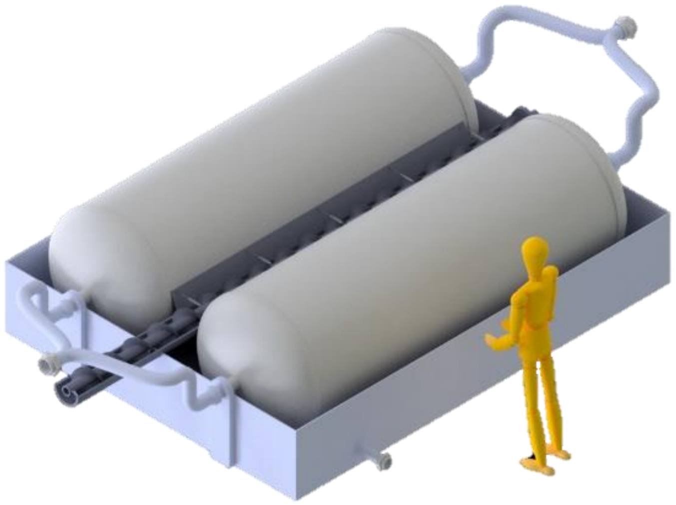
Conclusion

- Constant and controllable heat transfer during the discharge of a latent heat storage
- Adhesion of liquid PCM increases the heat transfer
- Adhering layer thickness can be reproduced by a analytical approach by Gel’perin
- Heat transfer composed out of phase change enthalpy and thermal conductivity from overheated liquid PCM
- Next Step: Validation of the technology using a high temperature PCM for steam generation

Thank you



1 MW at
ΔT = 10 K

6 MW at
ΔT = 100 K

Potential of the Rotating Drum Heat Exchanger for evaporating Water when using Sodium Nitrate as PCM