Composite materials for solid sorption heat pumps: measurements, model calculations and consequences for system performance

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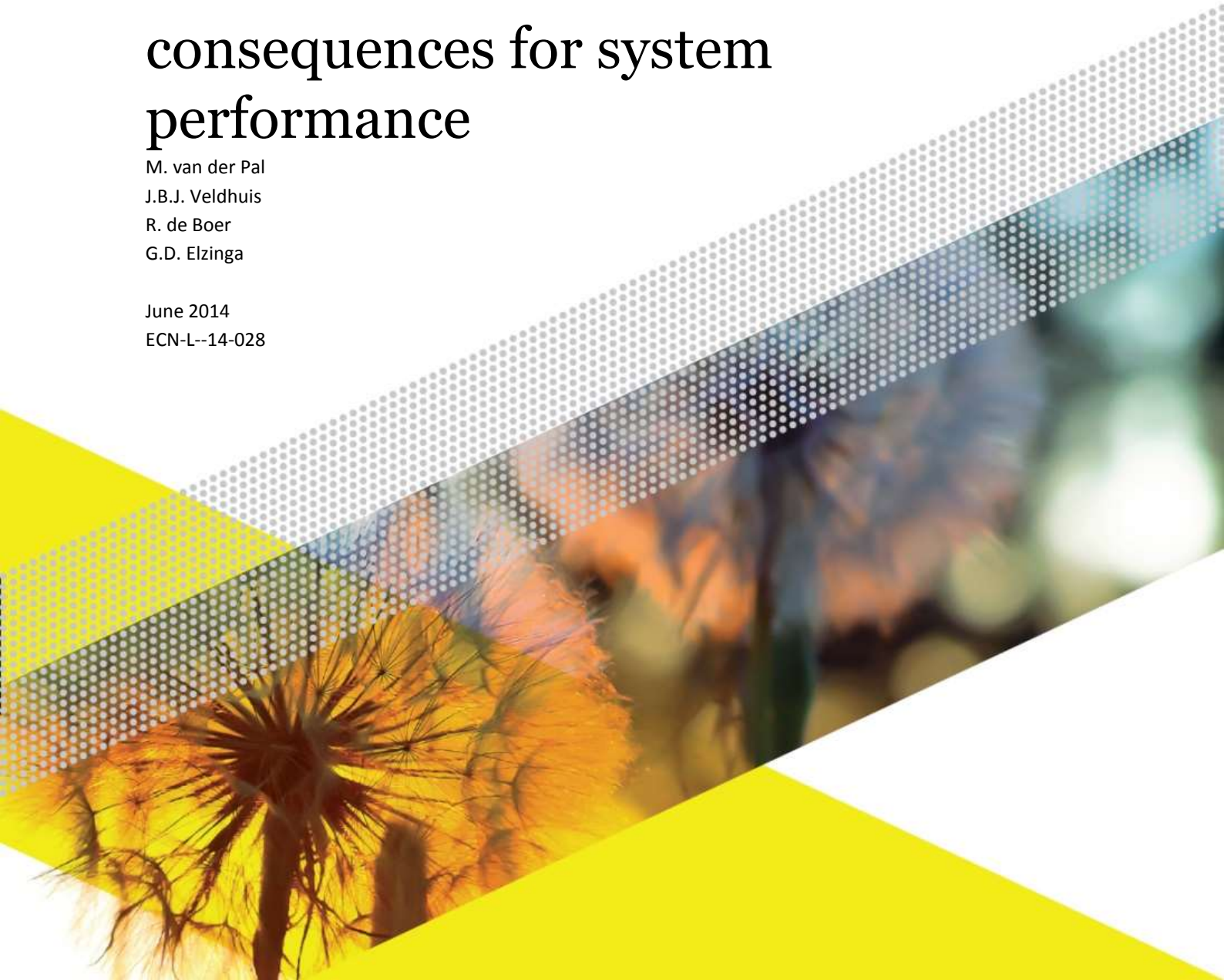

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Composite materials for solid sorption heat pumps: measurements, model calculations and consequences for system performance

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Contents

Introduction

- ECN is working on thermochemical heat transformers based on:
  - $LiCl(1\text{-}3)NH_3$ reaction in combination with $MgCl_2(2\text{-}6)NH_3$ for upgrading industrial waste heat to process heat
  - $CaCl2(2\text{-}4\text{-}8)NH_3$ reaction in combination with $MnCl2(2\text{-}6)NH_3$ and a compressor for upgrading low temperature waste heat to process heat

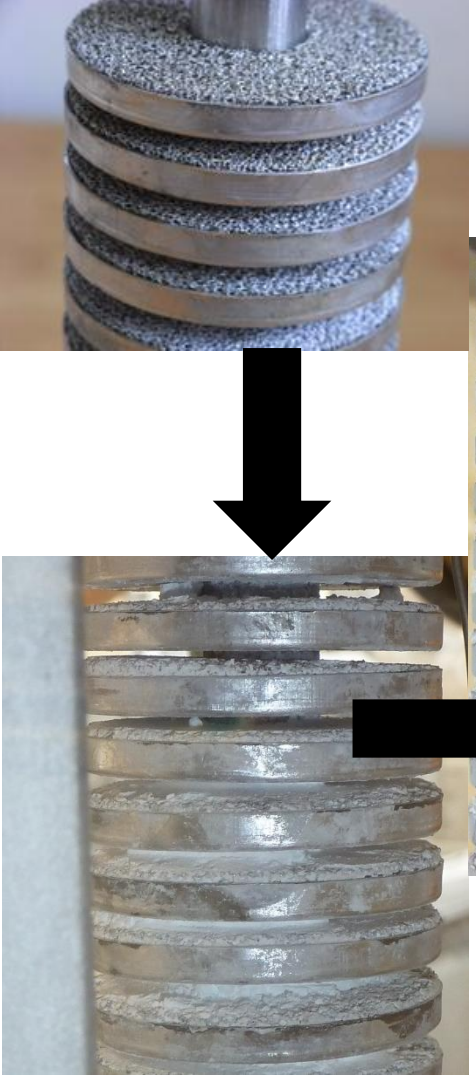
- Crucial for success of heat transformer:
  - Sufficient transfer(rate) of sorption heat to/from salt from/to Hex
  - Stable operation over many cycles

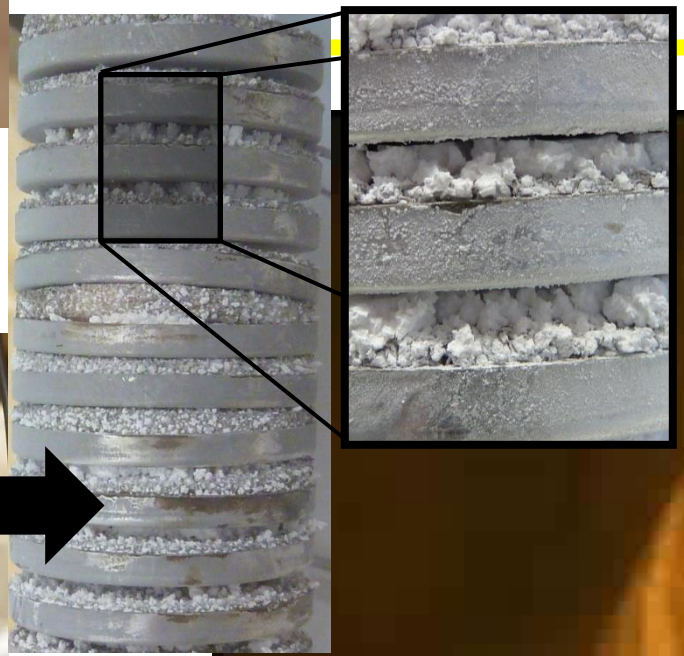
Why composite materials?

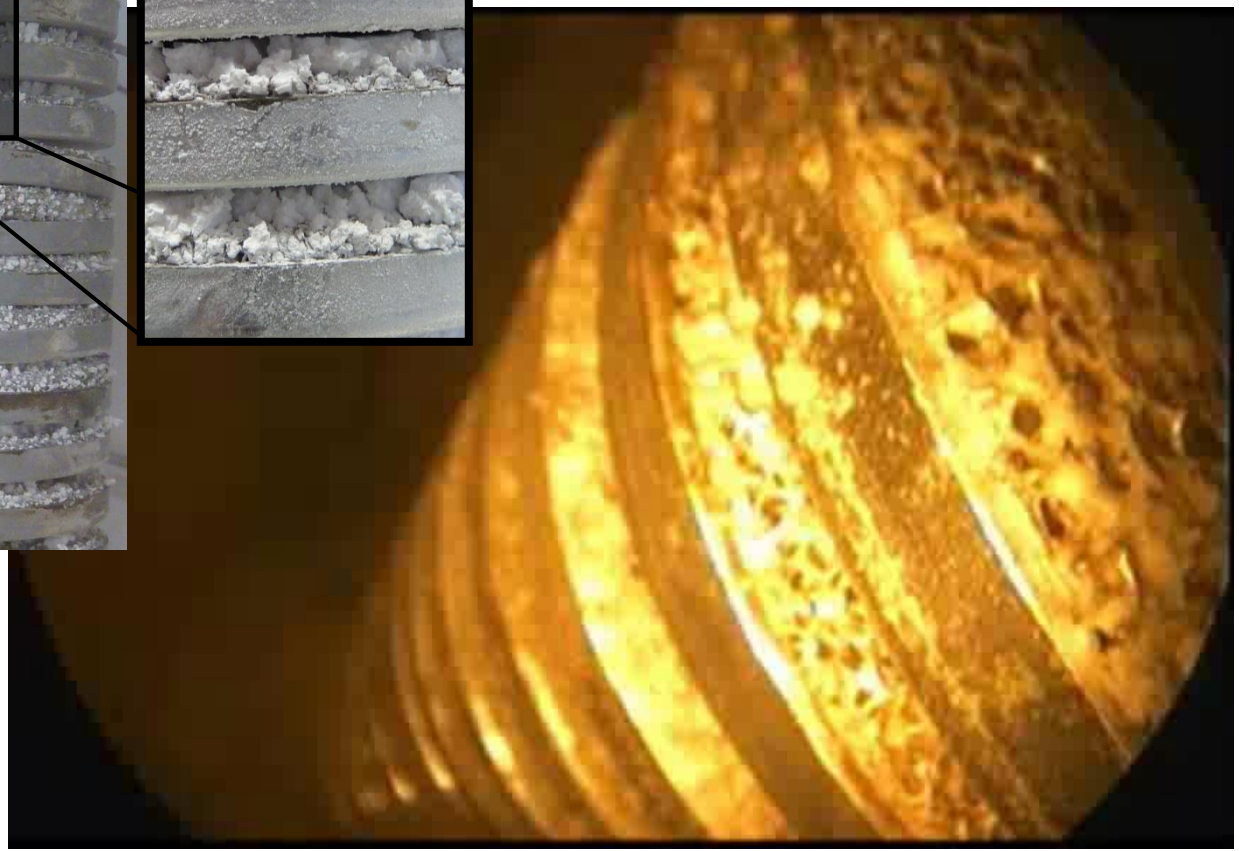
- Typical ammonia-salts properties are:
  - Poor thermal conductivity: only reasonable power density with thin layers = low COP
  - Poor strength: cannot create thick layers of salts with stable conditions
  - Volume changes: resulting in poorer connection with HEx
  - Tendency to become smaller and smaller crystals: loss of salt

- Composite materials can:
  - Improve thermal conductivity, resulting in shorter cycle times = higher power density
  - Provide structure for salts, including porosity and room to swell/shrink
  - Immobilise the salt

Attempts so far…







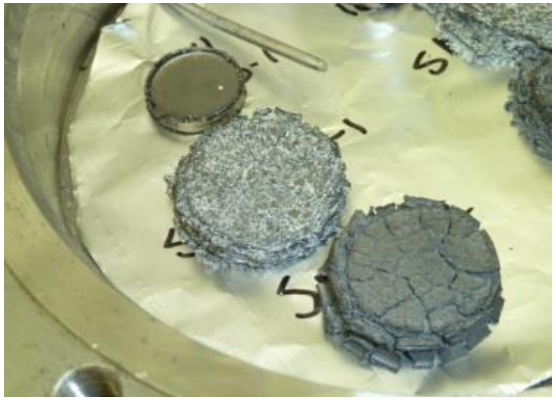
Composite selection and preparation

- Based on literature most promising material for salt-composite: ENG

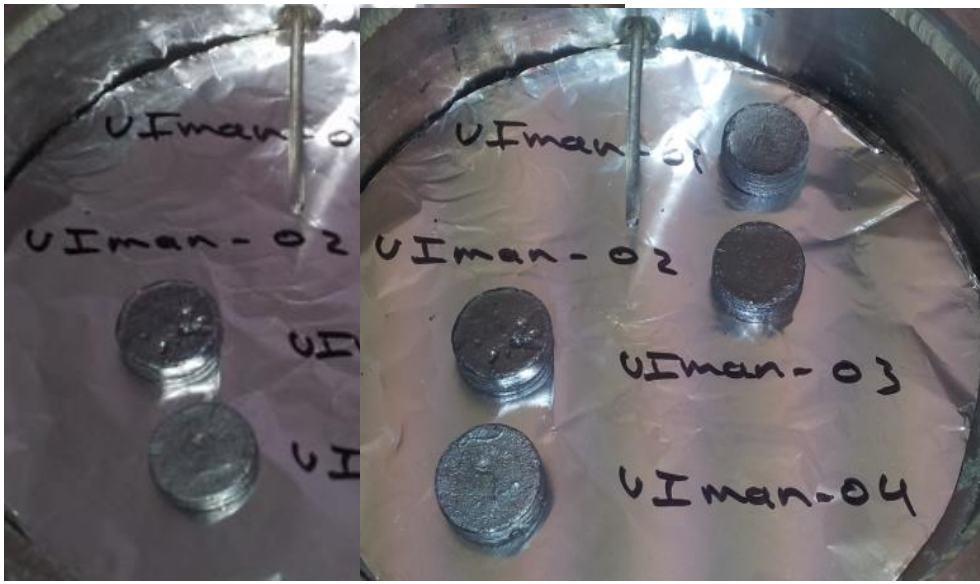
- Preparation based on literature info
  - Method 1: mixing of ENG and salts followed by pressing to desired density
  - Method 2: pressing (or purchasing) ENG to desired density followed by impregnating with salt from solution

Results preparation

Solids mixing of ENG and salts



Impregnating ENG with salts



Analyses

- Thermal conductivity using Hotdisk thermal conductivity meter
- Cycle stability using micro flow reactor

Hotdisk measurement

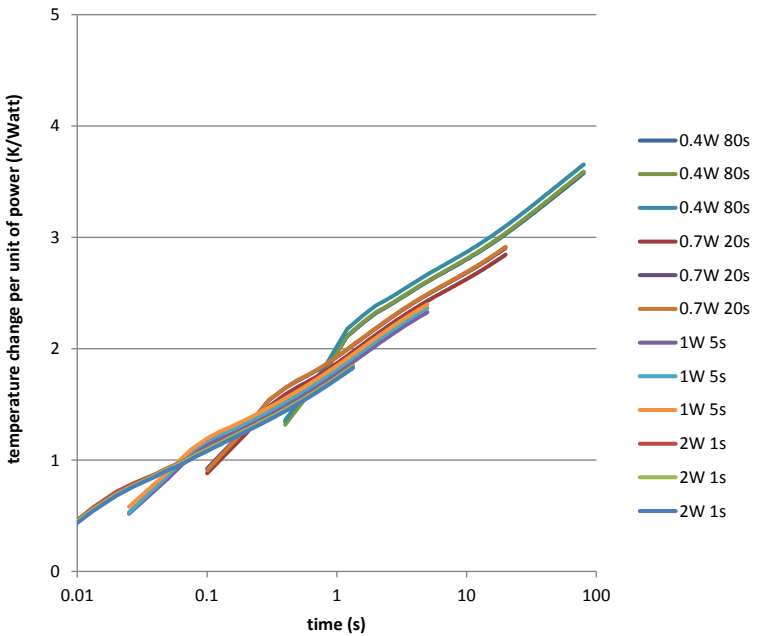
Principle:

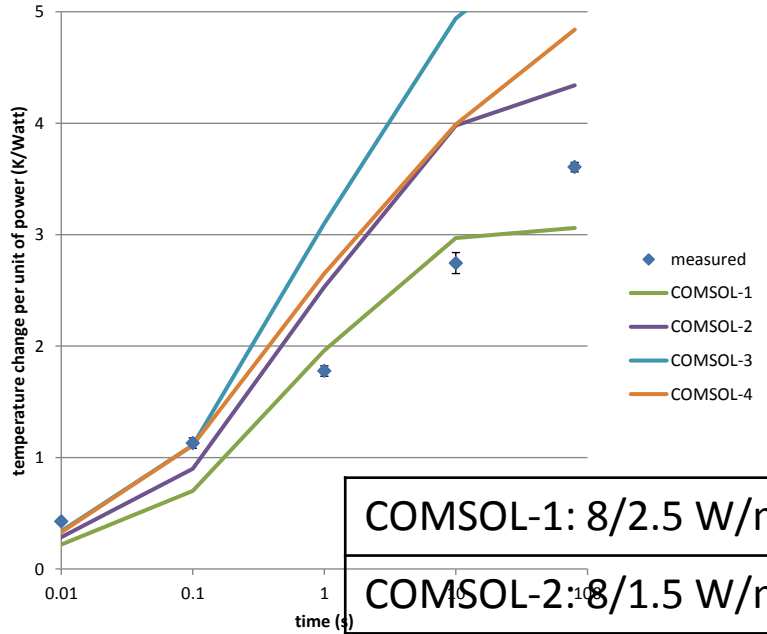
- Transient plane method
- Constant heat flux provided by sensor for set period
- Simultaneous with heat flux: measurement of electrical resistance of sensor →proportional to temperature

Hotdisk measurement

- Assumed:
  - $\lambda_{radial} \neq \lambda_{axial}$
  - Heat capacity = sum of heat capacity ENG and heat capacity $CaCl_2$
  - No heat flow at sides of the sample
  - Temperature top of the sample is equal to ambient
- Conditions:
  - Temperature increase measured in 1 to 80 seconds intervals with power input chosen for optimal temperature rise (too low = poor signal/noise ratio, too high = too many second-order effects)
  - ENG measured with and without $CaCl_2$
- Analysis:
  - Comparison with COMSOL model with various values for λ_{radial} and λ_{axial}

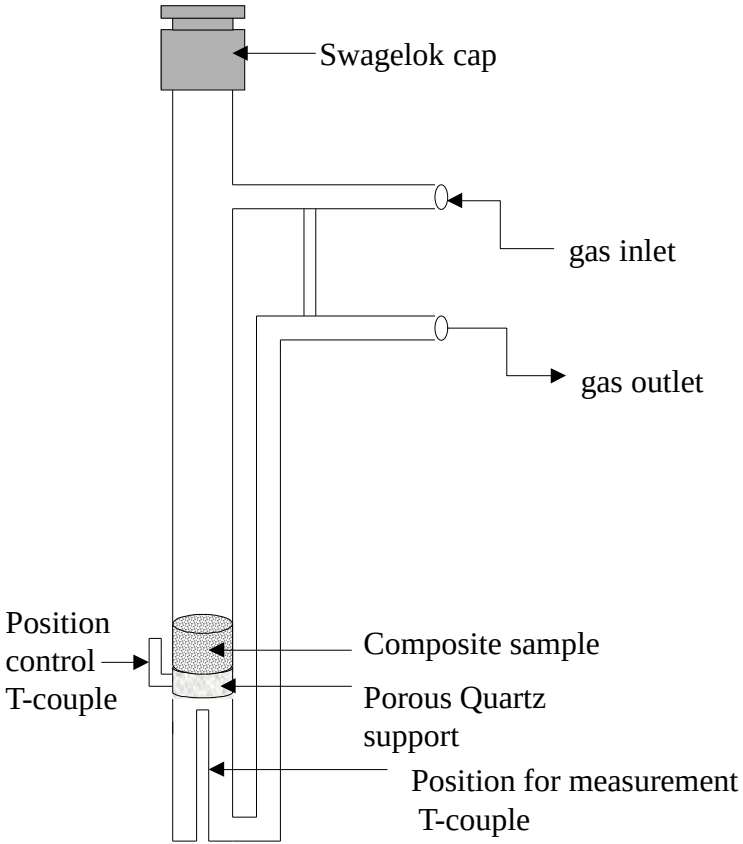
Hotdisk results for ENG-$CaCl_2 \cdot xNH_3$

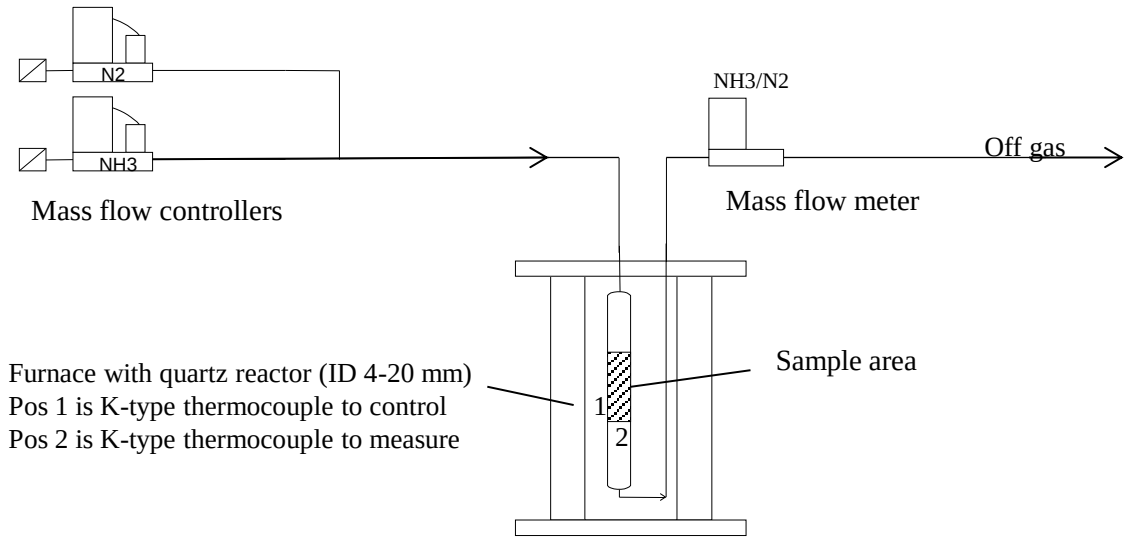




COMSOL-1: 8/2.5 W/mK
COMSOL-2: 8/1.5 W/mK
COMSOL-3: 8/1.0 W/mK
COMSOL-4: 16/1 W/mK

Setup: Micro flow reactor





Micro flow reactor measurement

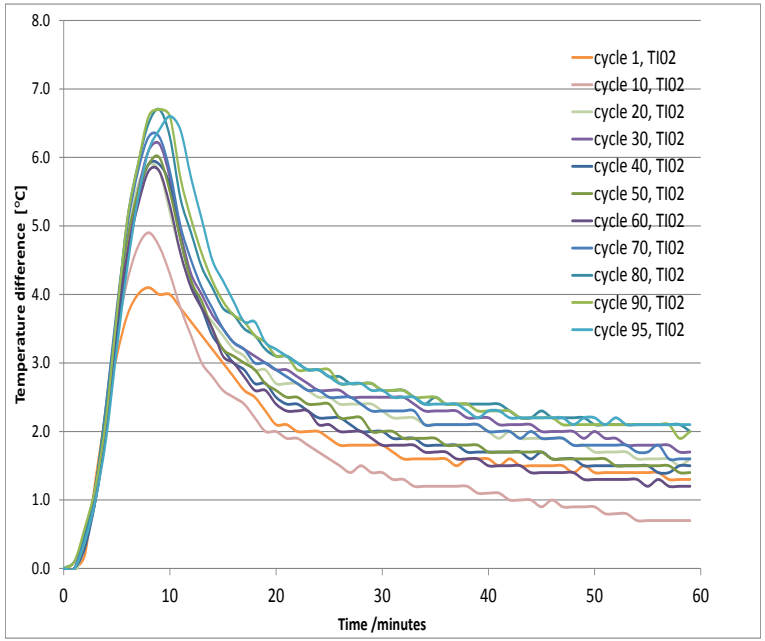
- Reactor and gas temperature set at constant value of 40°C
- Mass flow controller set at 10 ml/min
- Sample using ENG + $CaCl_2$
- Over 100 times: 1 hour NH_3 flow (adsorption), 1 hour N_2 flow (desorption)

- Measured parameters:
  - Flow out
  - Temperature composite
  - Temperature gas

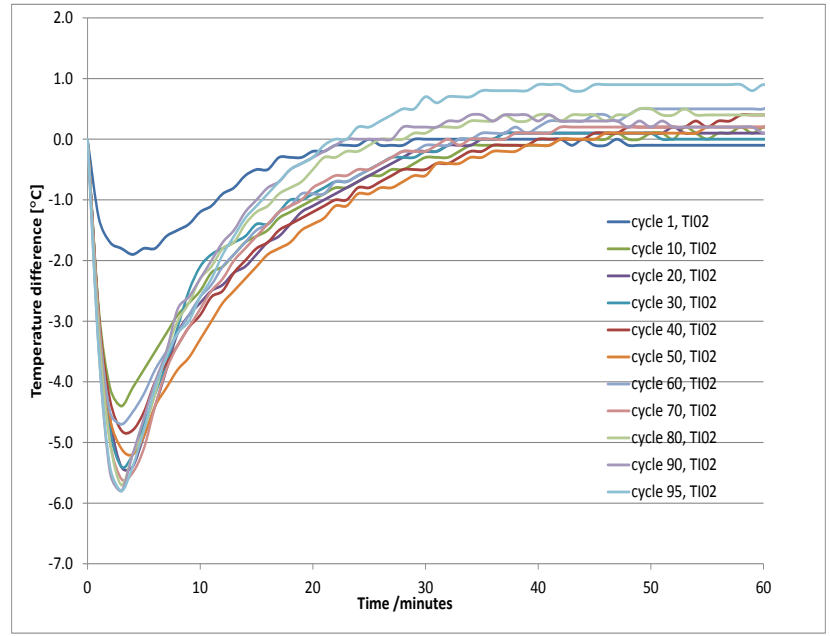
- Visual inspection after 100+ cycles

Temperature profiles cycle tests

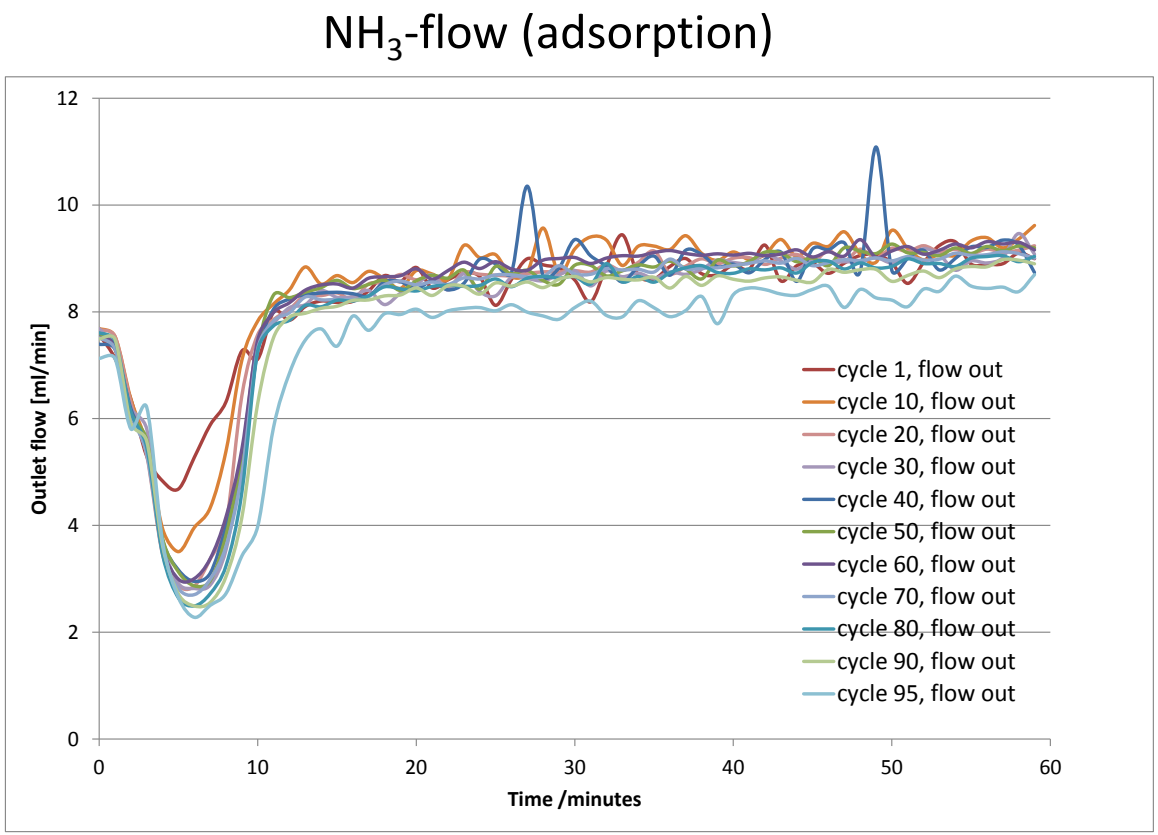
NH_3-flow (adsorption)



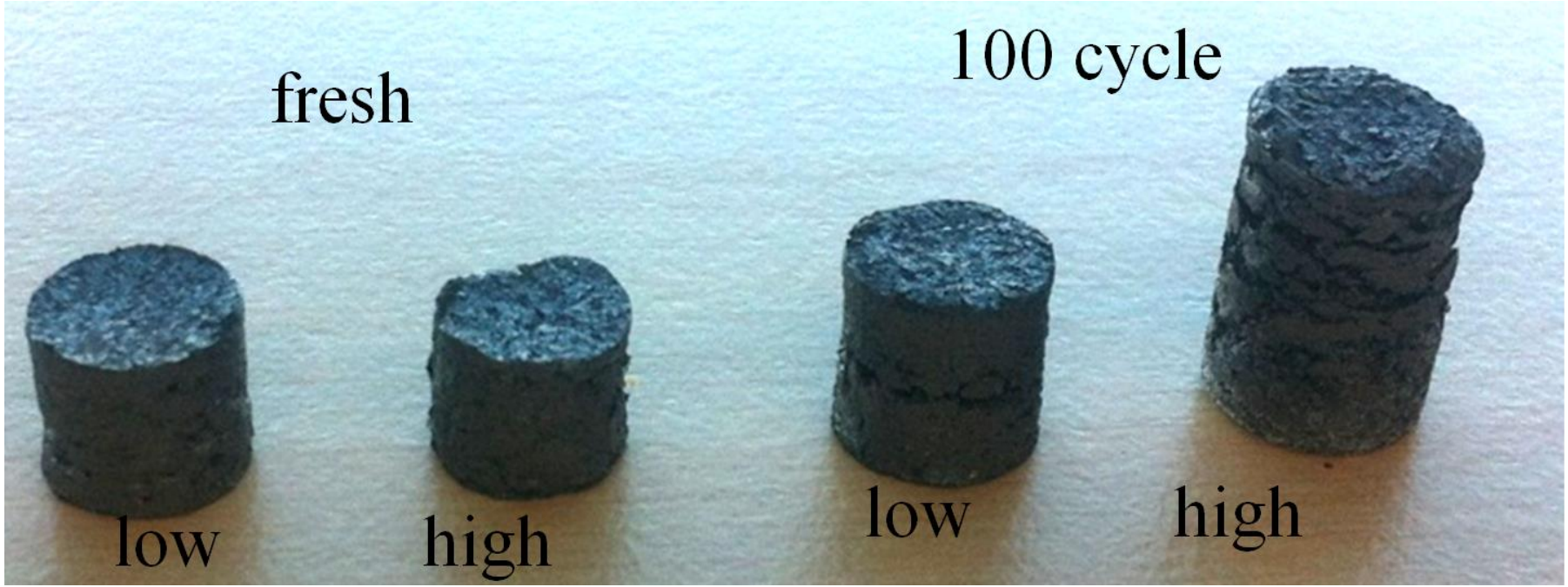
N_2-flow (desorption)



NH3 flow out profiles cycle tests



Materials before and after 100+ cycles



Discussion and conclusions

- Hotdisk measurements:
  - Thermal conductivity of ENG+$CaCl_2$ seems very comparable with ENG properties
  - Assumed/unknown: do ENG and salt heat up at the same time?
  - COMSOL model calculations give good insight but less suited for quantifying thermal conductivity very precisely

- Microflow measurements:
  - Experimental method successful for determining composite stability regarding sorption behavior
  - Stable operation after first 10 cycles
  - Effect on material itself cannot be determined, visual inspection required
  - Setup allows for long-term testing of material (10,000+ cycles)

Questions?

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