The effect of unevenly spaced parallel plates in regenerators

Delft Days on Magnetocalorics

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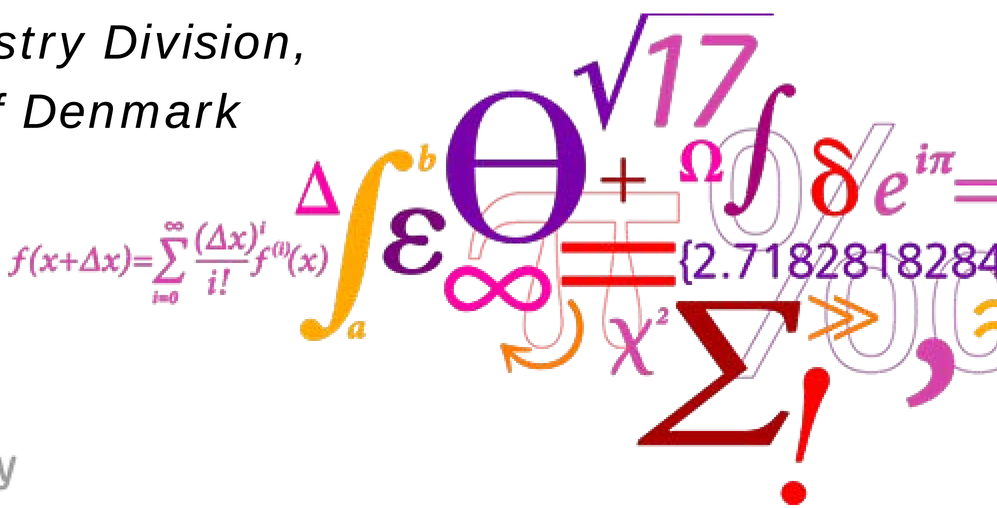
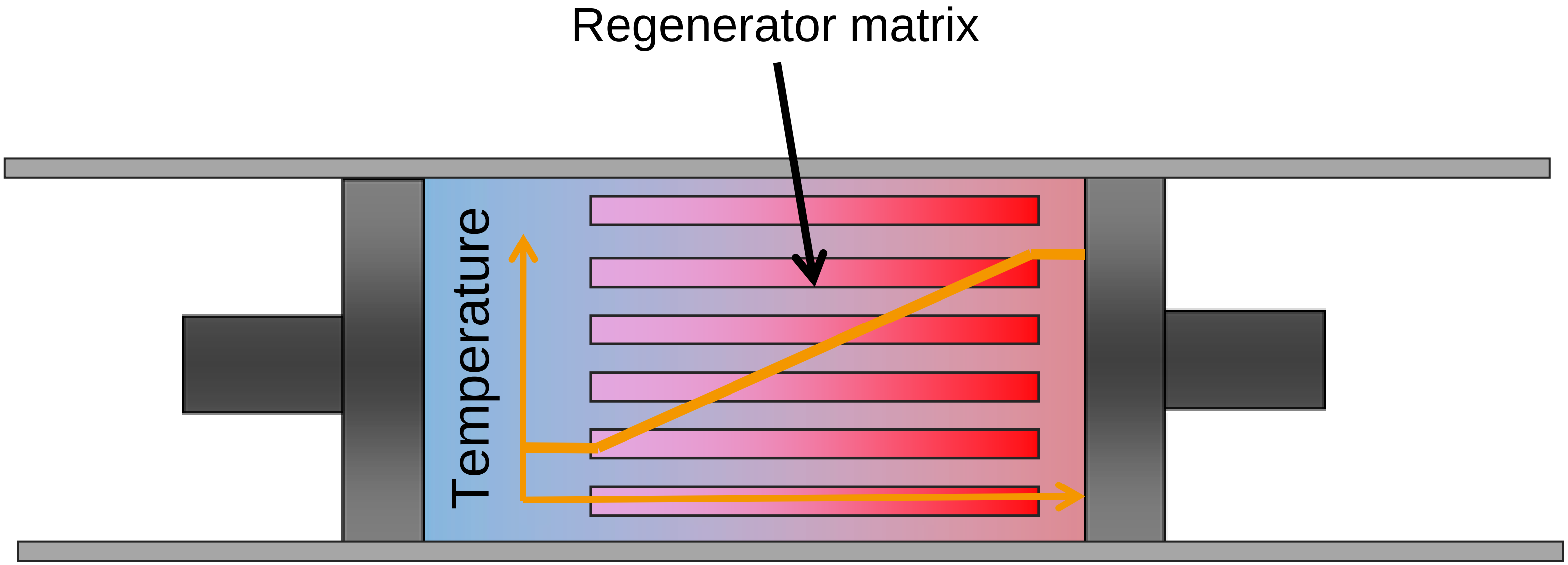


Outline

- Theoretical considerations of regenerators / heat exchangers
- Measuring the plate thicknesses and spacings of parallel-plate stacks
- Thermal and fluid-dynamical modeling of an inhomogeneous flat plate stack
- Results
- Conclusions

The active magnetic regenerator

Purpose of the regenerator:
To have sufficient heat transfer between fluid and solid during relevant operating conditions



Regenerator geometries

- Problems / issues:
  - Sufficient heat transfer
  - Pressure drop across the bed
  - Constructability
  - Geometric effects on the internal magnetic field

- The most applied geometries so far are:
  - Packed spheres / irregular particles
  - Parallel plates

The efficiency of a thermal regenerator

- The performance of a thermal regenerator is directly related to the Number of Transfer Units (NTU) defined as:

$$NTU = \frac{hA_{HT}}{\dot{m}c_f} = \frac{k_f}{2m_s c_s \varphi} \frac{NuA_{HT}}{d_h f}$$

$$k_f = \text{Thermal conductivity of fluid}$$

$$m_s c_s = \text{Thermal mass of solid regenerator}$$

$$\varphi = \text{Thermal utilization of the regenerator} = \frac{\dot{m}_f c_f}{2 f m_s c_s}$$

$$Nu = \text{Nusselt} - \text{number} = \frac{hd_h}{k_f}$$

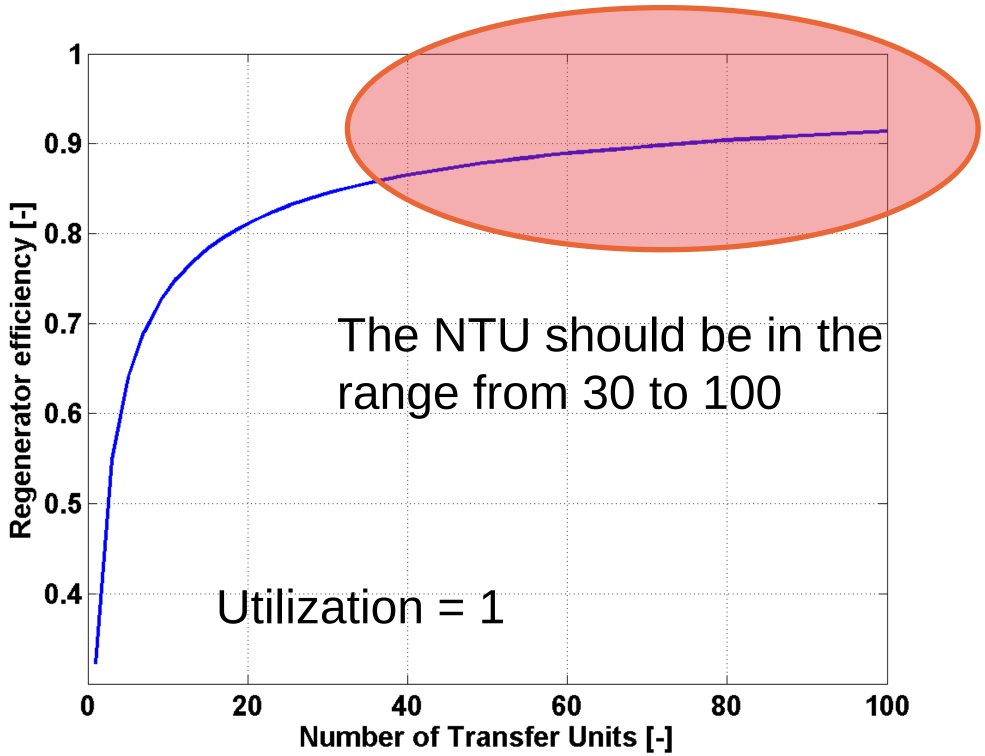
$$A_{HT} = \text{Wetted heat transfer area}$$

$$d_h = \text{Hydraulic diameter of the regenerator}$$

$$f = \text{Device operating frequency}$$

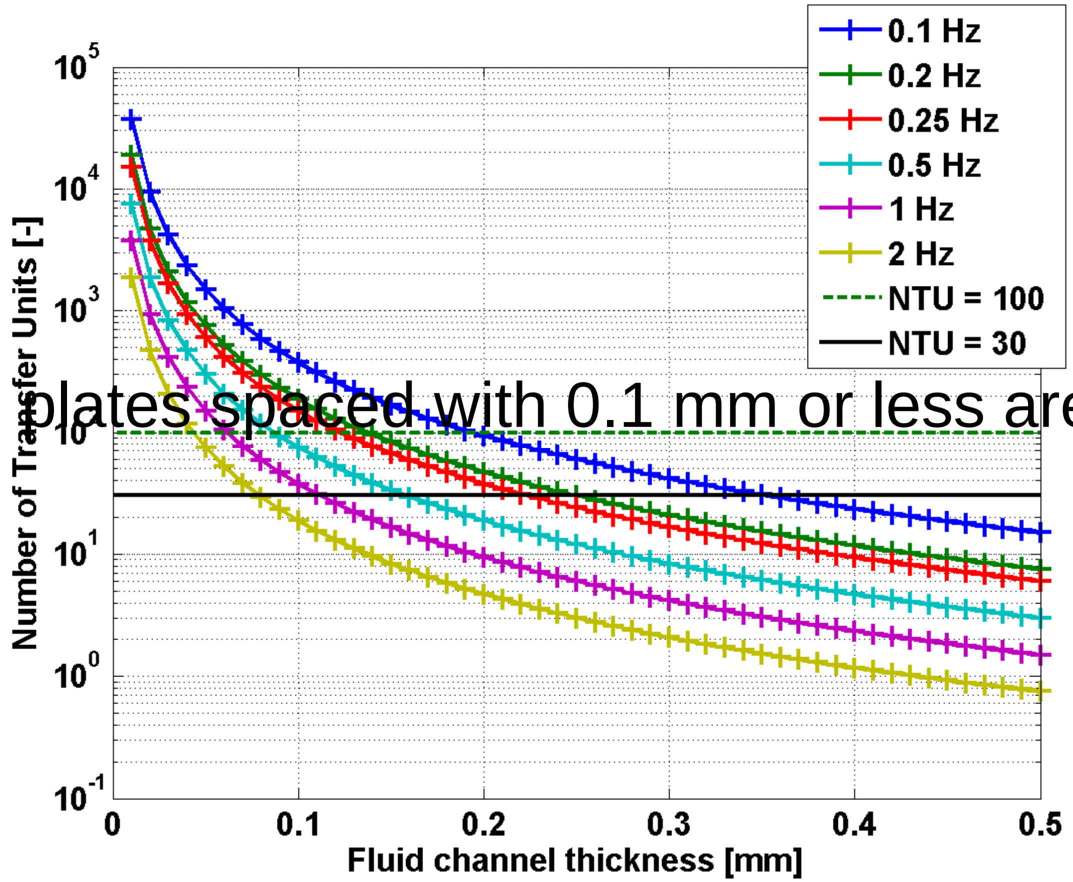
Efficiency-NTU

Region of interest
(found through extensive modeling with detailed AMR models)



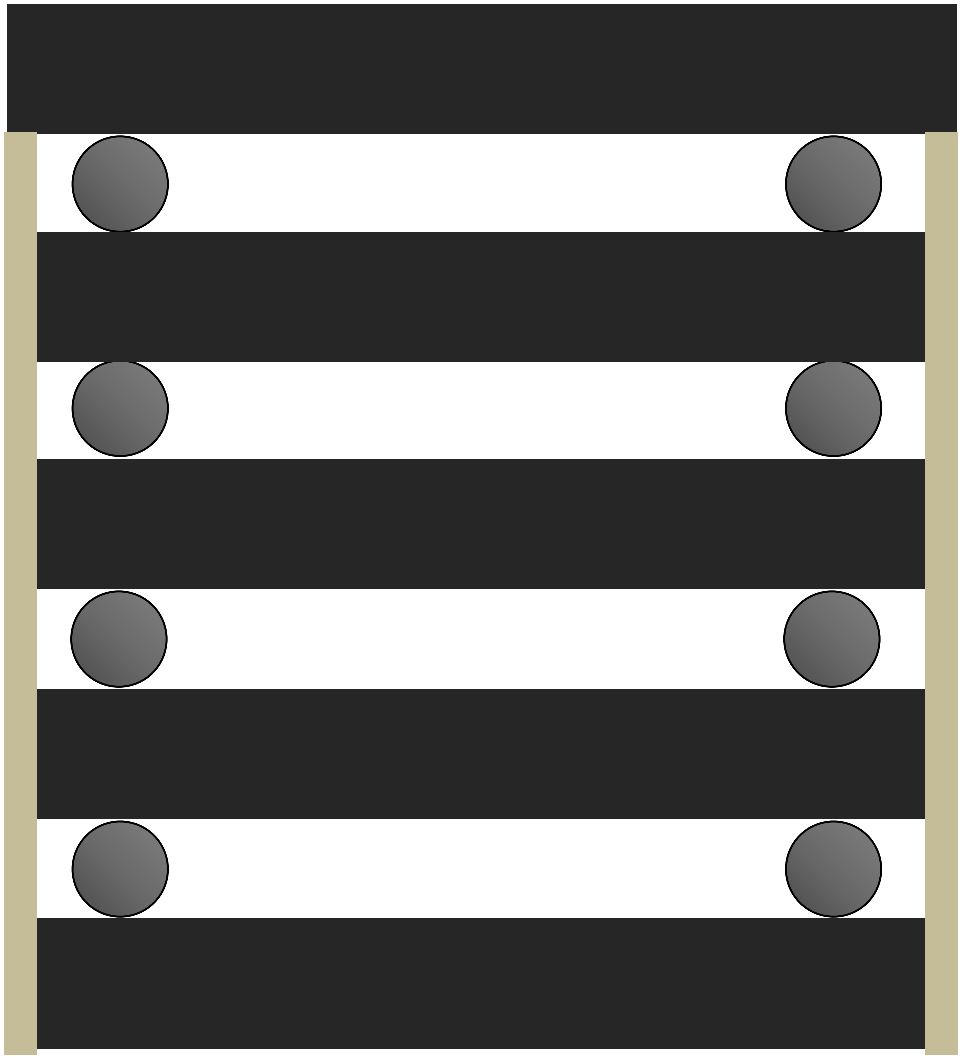
Look-up table results from Dragutinovic & Baclic, 1998

Flat, parallel plates (with Gd-like properties)



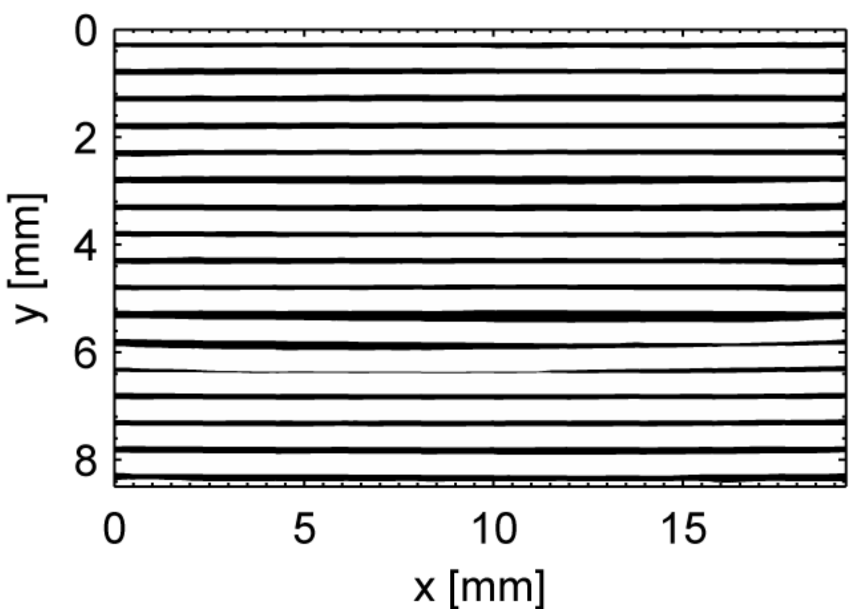
Thin (and flat) plates spaced with 0.1 mm or less are thus required!

Construction and evaluation of the performance of flat plate stacks

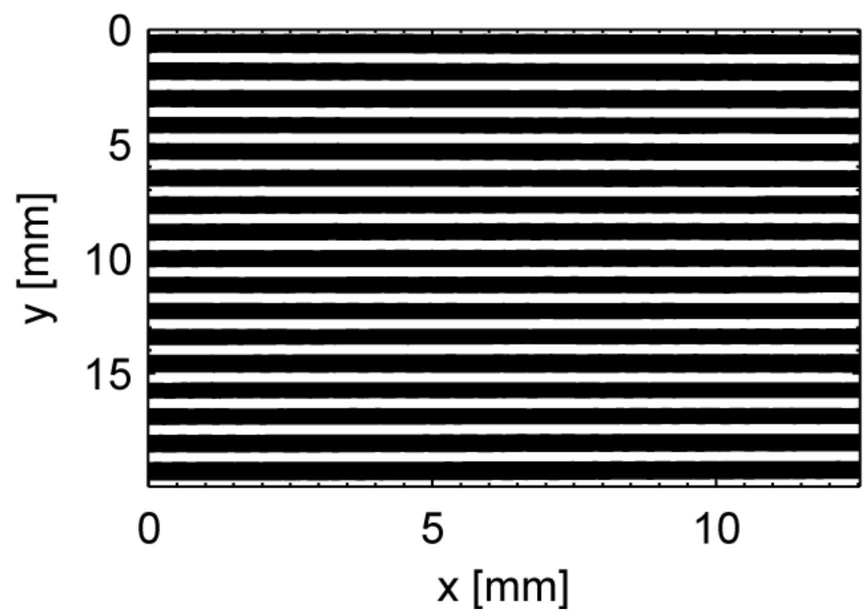


Examples of produced stacks

Nominal spacing: 0.1 mm



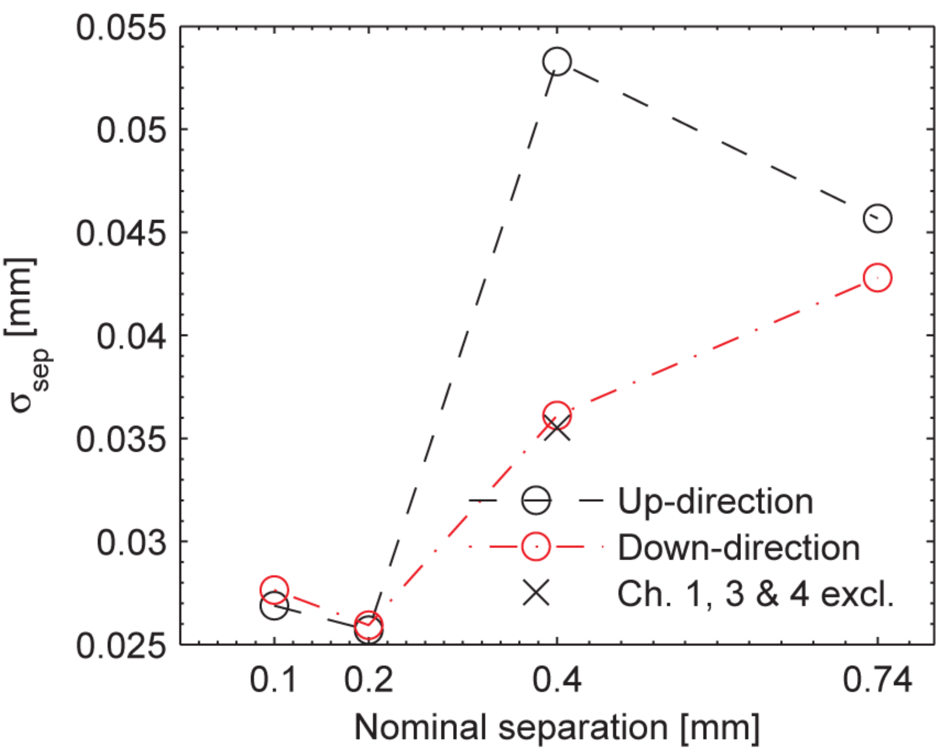
Nominal spacing: 0.7 mm



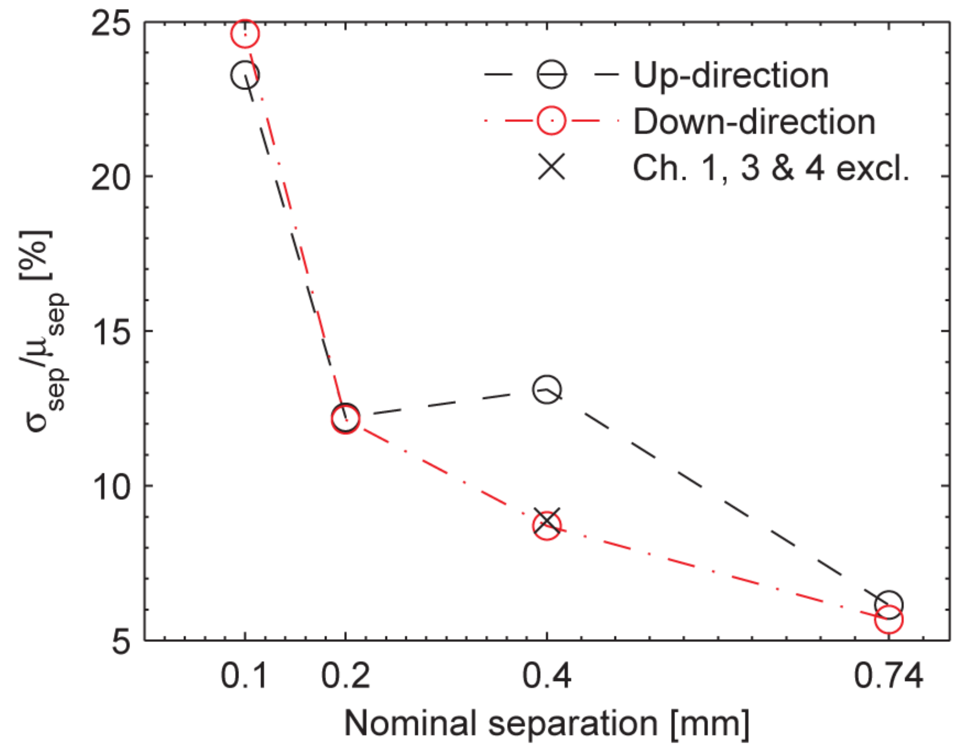
A total of four stacks of aluminum sheets (40x25x0.4mm) each consisting of 18 plates was constructed using the same technique

Measured plate spacings

Absolute standard deviation [mm]



Relative standard deviation [%]

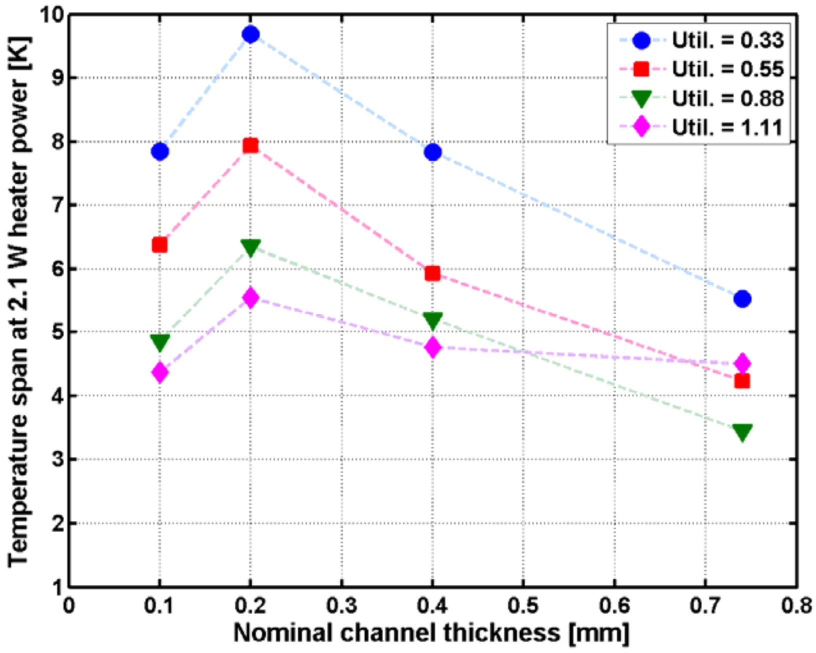


Experimental

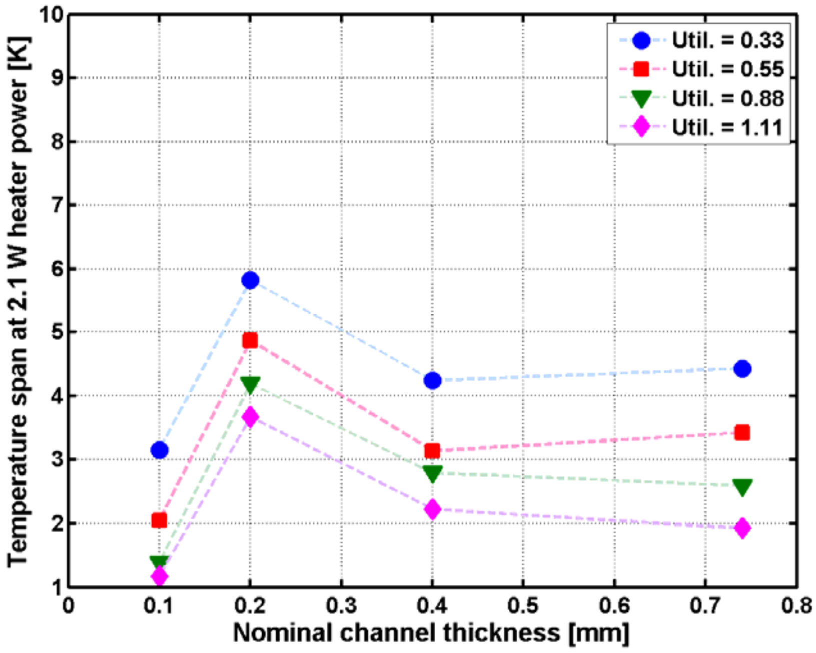
- The Risø DTU AMR test machine was applied in a passive regenerator setup
- This was realized by maintaining a constant temperature at one end (the cold end) and applying a constant heat load the other end (the hot end).
- The steady state performance measured as the temperature span between the hot and cold ends is a direct measure of the regenerator efficiency.

Results

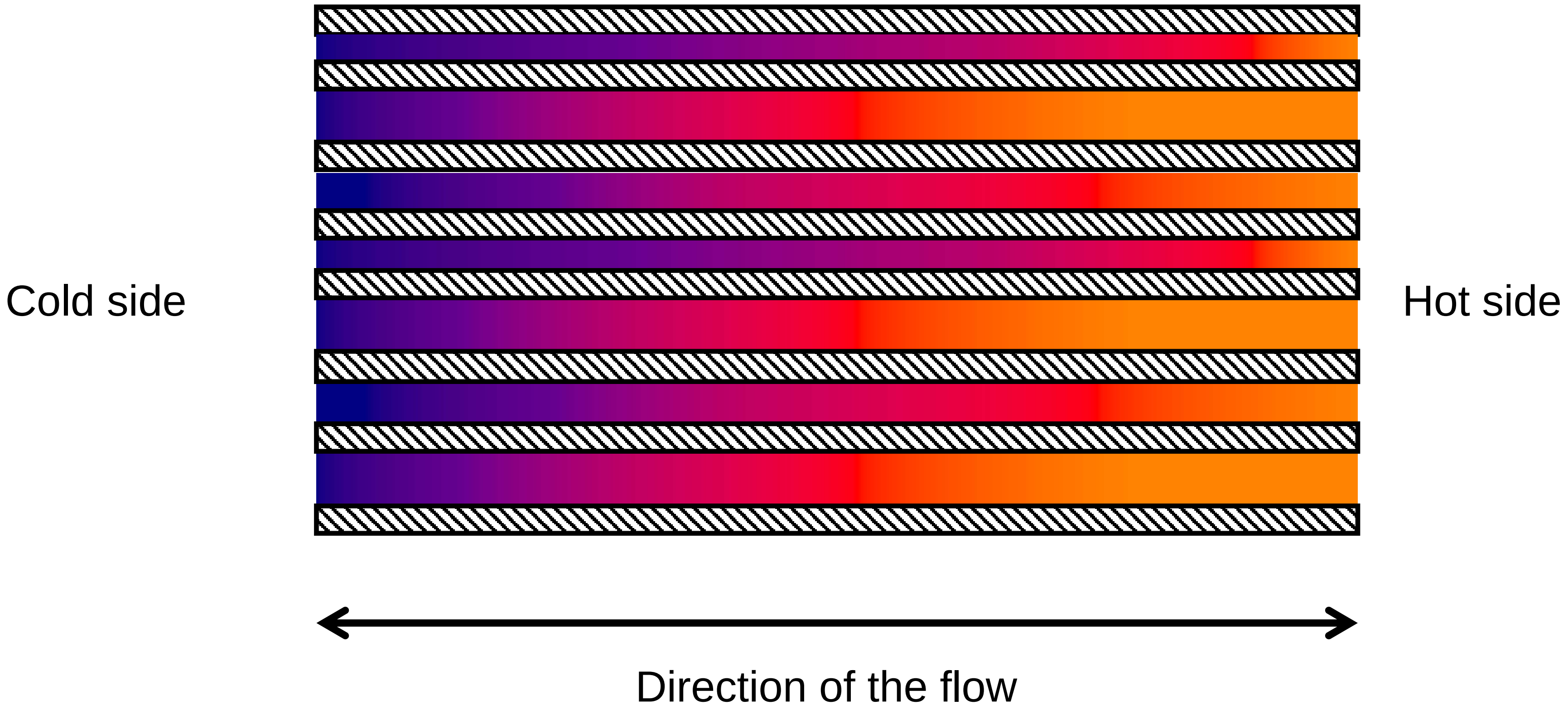
Low flow rate (high NTU)



High flow rate (low NTU)



Flow and heat transfer in an inhomogeneous stack of flat plates



Numerical modeling of an inhomogeneous stack of parallel plates

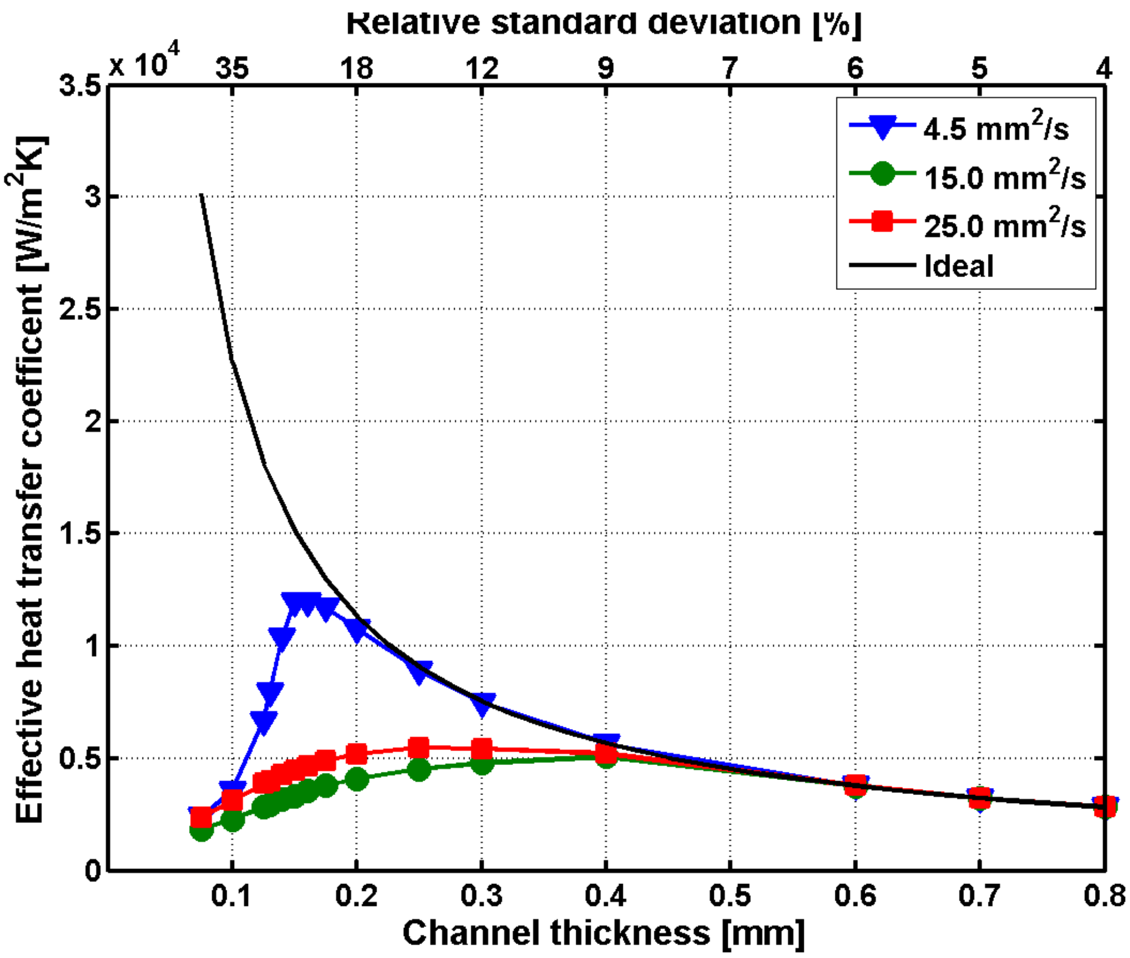
- A 2-dimensional model was implemented in COMSOL with a varying number of plates and fluid channels

- It is assumed that
  - The fluid enters in a well-distributed manner
  - The pressure drop is the same in each individual channel
  - The fluid mixes perfectly at the outlet

- Running the model with a single blow of fluid allows for a direct comparison to the ideal single channel / single plate case

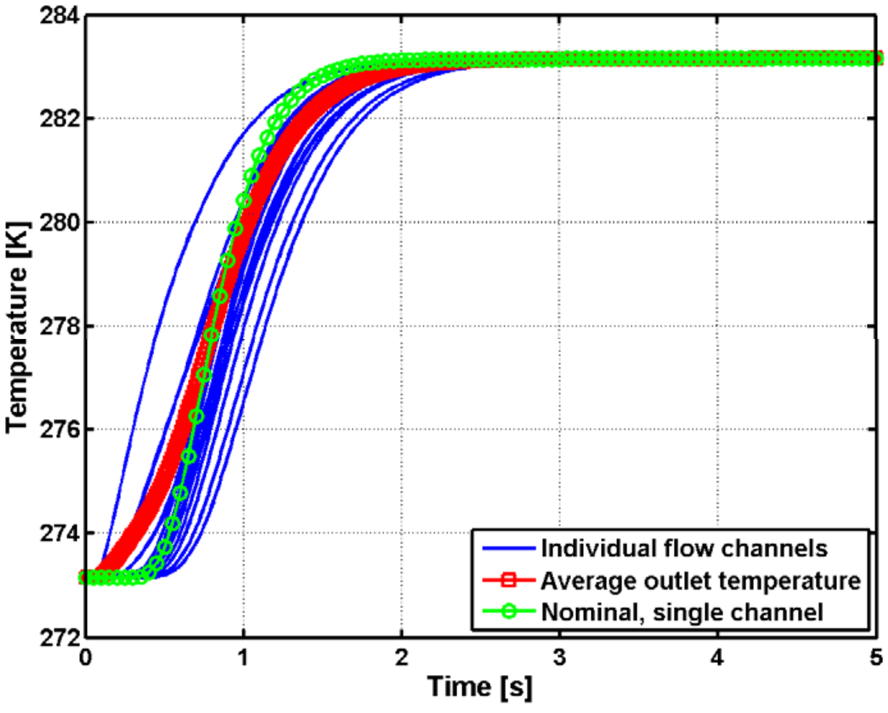
- An effective heat transfer coefficient of the overall stack may thus be found using standard techniques

Numerical results

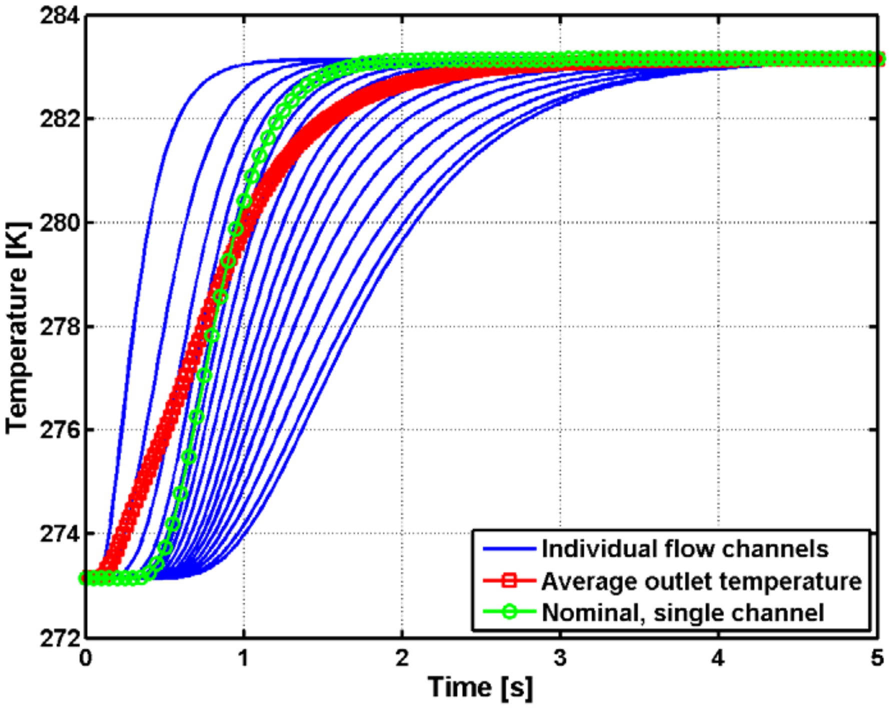


Thermal cross-talk in an inhomogeneous stack

Actual constructed stack
(”random” distribution of channels)



Channels sorted in size



Conclusions

- The quality of the plates (i.e. their flatness) is very important
- The spacing of the plates is equally important.
- In an inhomogeneous stack the flow will be maldistributed leading to un-desired conjugate heat transfer and thermal cross-talk
- These are two effects that are important in other micro-channel designs than parallel plates as well
- In order to reach operating frequencies above 1 Hz using parallel plates or similar, their spacing will have to be 0.1 mm or less. That poses a great challenge for people developing materials and constructing regenerators!

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