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Numerical modeling of parallel-plate based AMR

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Outline

- The Danish effort in magnetic refrigeration
- Focus on the modeling
- Results from both experiment and modeling
- Discussion

Risø's work on magnetic refrigeration

Partnership between

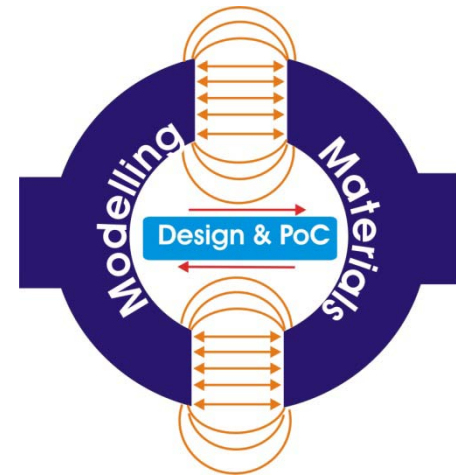


Duration: 4 years

- Starting date: 01.01.2007
- Ending date: 31.12.2010

Funding: €2.6M

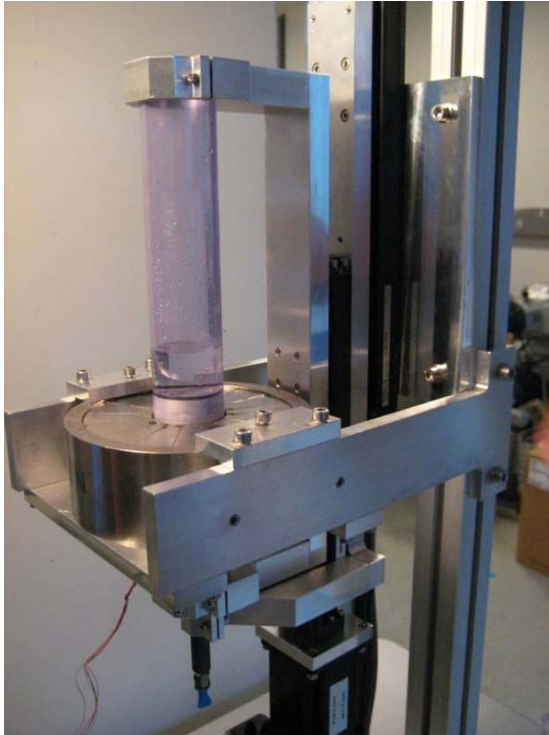
- 5 Ph.D. students
- 3 Postdocs



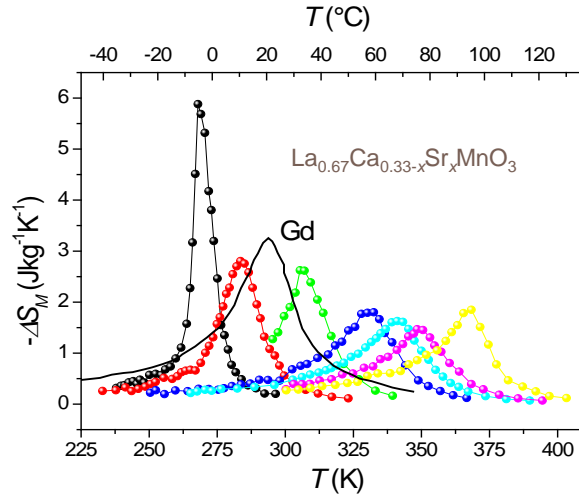
Challenges

Demonstrate cost-effective systems at commercially relevant temperature spans with high efficiency and environmentally friendly materials

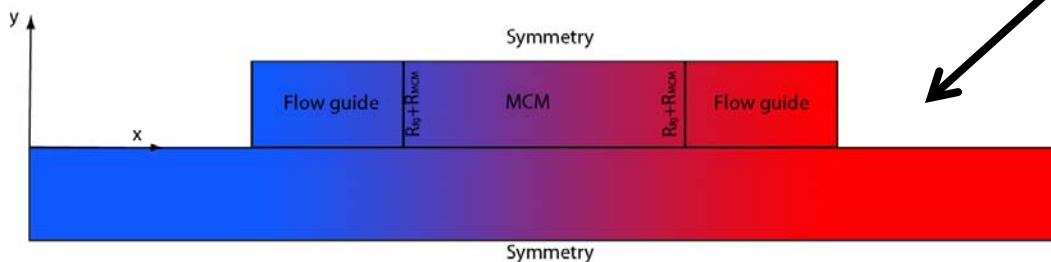
Configuration of our effort



Development of prototype



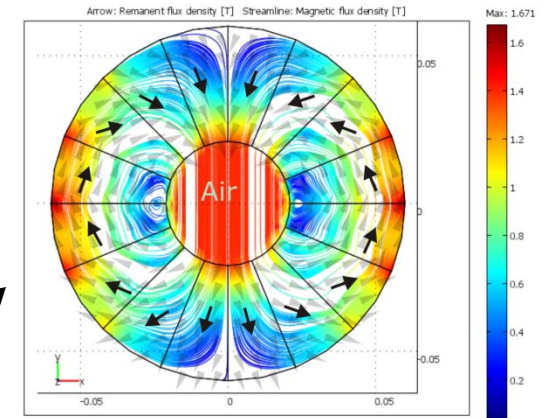
Modeling of both AMR and permanent magnet



Materials research:

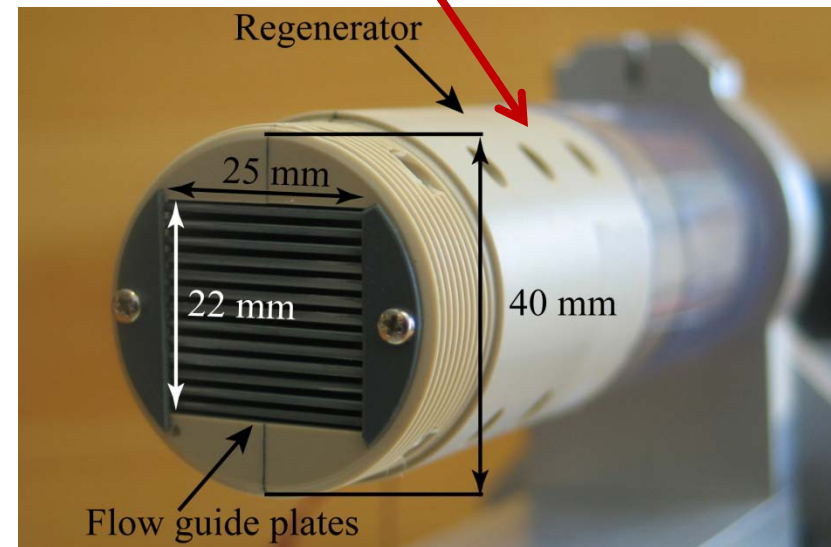
- New materials
- Characterization, evaluation and processing of relevant materials

Linear system
Halbach cylinder



Details on the experiment

- Parallel plate based AMR
- Reciprocating
- Permanent magnet
- Materials used include Gd and LaCaSrMnO_3
- Plate thickness from 0.3 to 0.9 mm
- Channel thickness from 0.5 to 1.0 mm

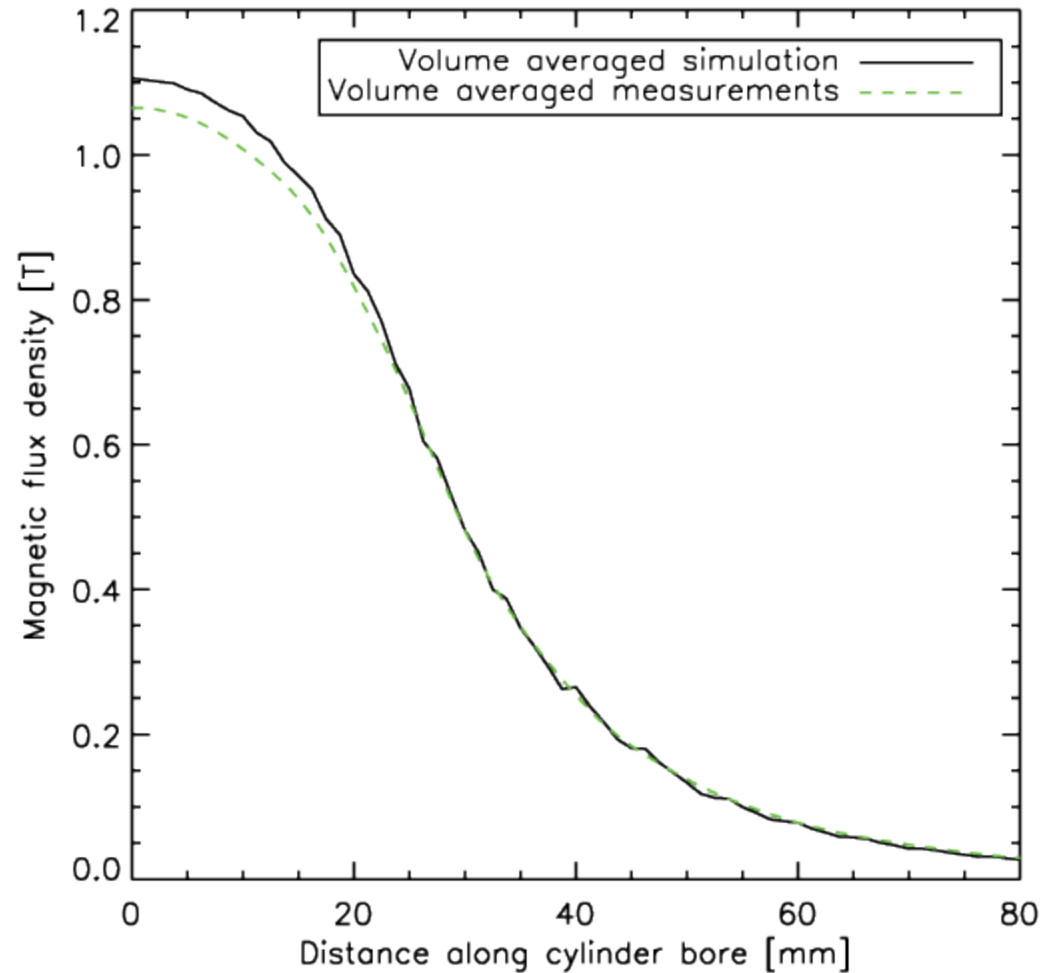
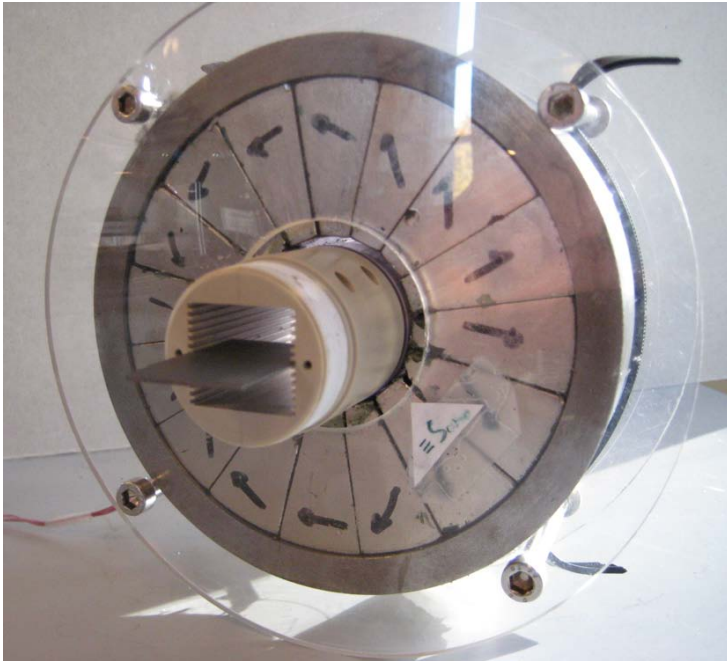


Plates for the regenerator

Example of $\text{La}_{0.67}\text{Ca}_{0.26}\text{Sr}_{0.07}\text{Mn}_{1.05}\text{O}_3$ plates
(40x25x0.3 mm)



The permanent Halbach magnet

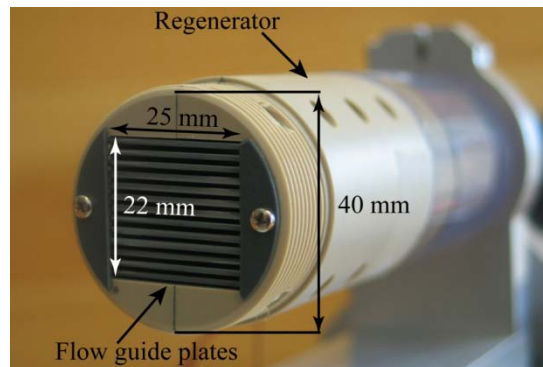
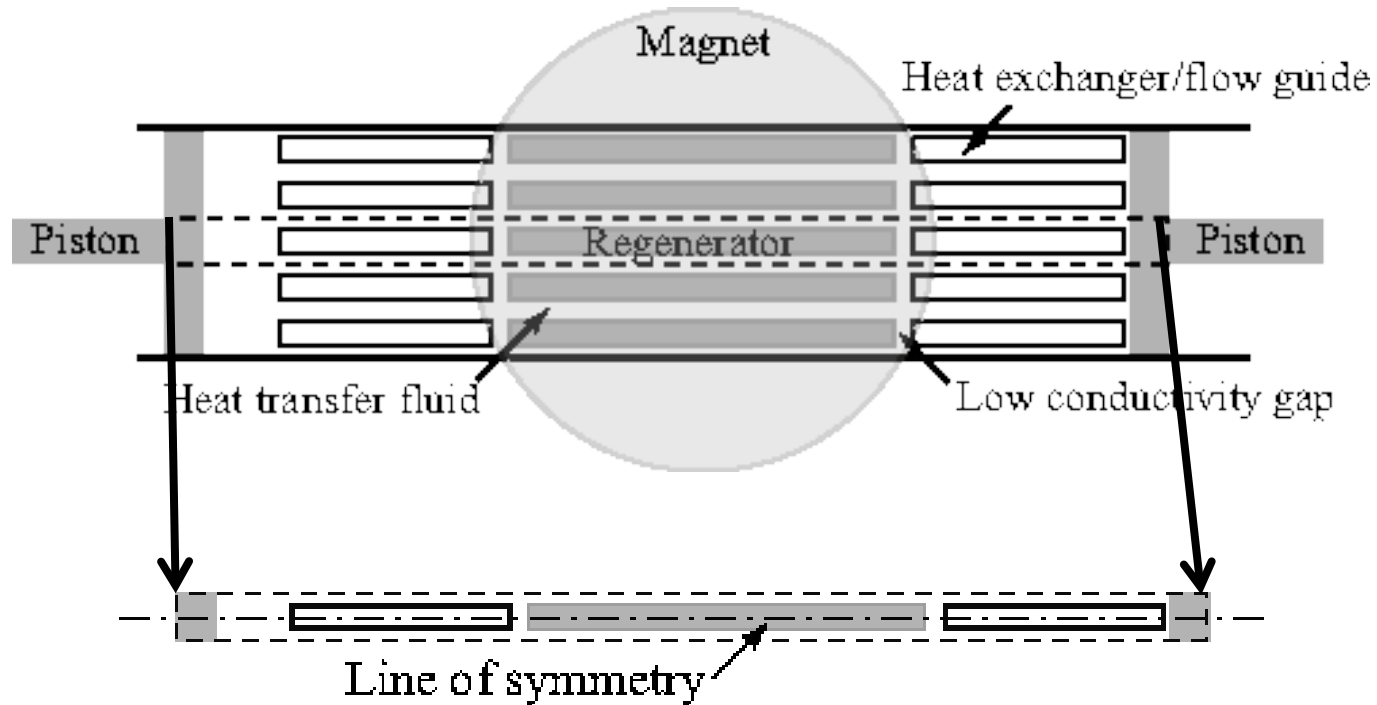


Numerical AMR modeling

Key features of our numerical AMR model

- 2.5-dimensional
- Parallel-plate based
- Versatile
- Fast!

Schematic of the model



Details of the model

$$\rho_{MCM} c_{p,MCM} \frac{\partial T_{MCM}}{\partial t} = k_{MCM} \nabla^2 T_{MCM} + Q_{MCE} + \frac{T_{\infty} - T_{MCM}}{dV \sum R_{MCM}} + Q_{bdry}$$

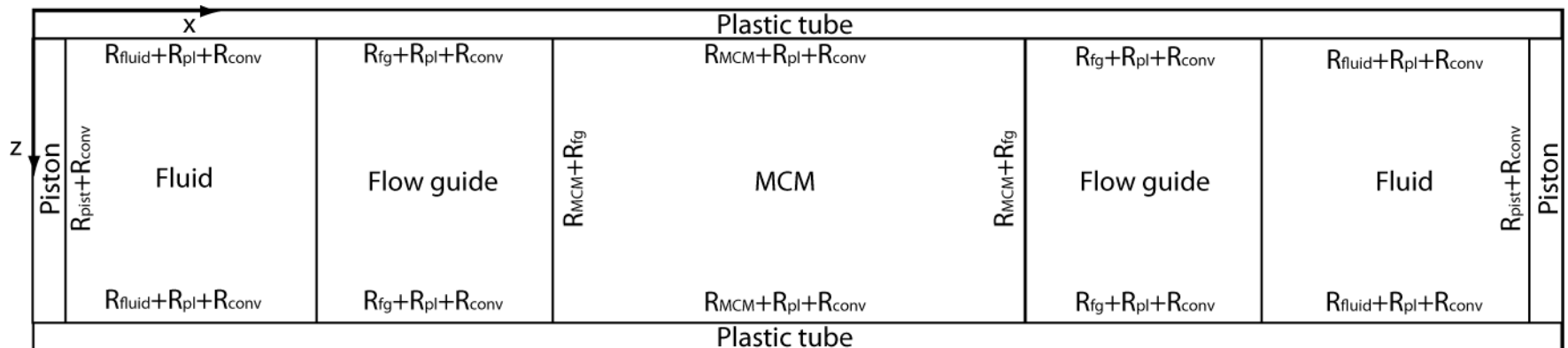
$$\rho_{fg} c_{p,fg} \frac{\partial T_{fg,1}}{\partial t} = k_{fg} \nabla^2 T_{fg,1} + \frac{T_{\infty} - T_{fg,1}}{dV \sum R_{fg}} + Q_{bdry}$$

$$\rho_{fg} c_{p,fg} \frac{\partial T_{fg,2}}{\partial t} = k_{fg} \nabla^2 T_{fg,2} + \frac{T_{\infty} - T_{fg,2}}{dV \sum R_{fg}} + Q_{bdry}$$

$$\rho_{fl} c_{p,fl} \left(\frac{\partial T_{fl}}{\partial t} + u \cdot \nabla T_{fl} \right) = k_{fl} \nabla^2 T_{fl} + \frac{T_{\infty} - T_{fl}}{dV \sum R_{fl}} + Q_{bdry}$$

The diagram illustrates a cross-section of a system with a central MCM (Micro Channel Module) layer, flanked by two Flow guide layers, all situated within a Fluid domain. The x-axis is horizontal and the y-axis is vertical. Thermal resistances are indicated at various interfaces: $R_{fg} + R_{fluid}$ at the flow guide-fluid interfaces, $R_{fg} + R_{MCM}$ at the flow guide-MCM interfaces, $R_{MCM} + R_{fluid}$ at the MCM-fluid interface, and $R_{pist} + R_{conv}$ at the outer boundaries. Arrows labeled "Symmetry" point to the central vertical lines of the MCM and fluid layers. The equations above describe the energy balance for each layer: MCM, flow guides, and fluid.

Details of the model

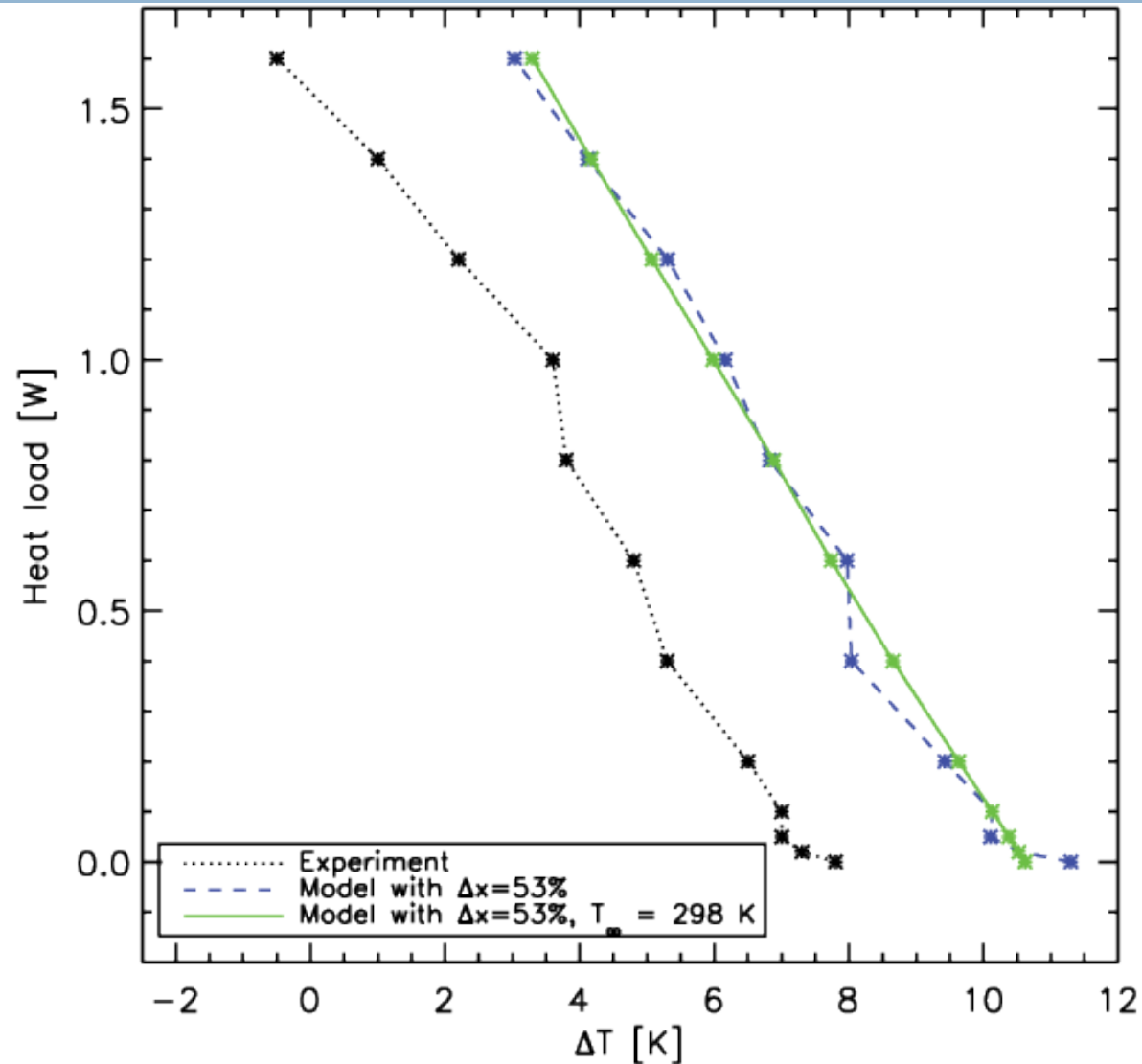


Experiments and modeling

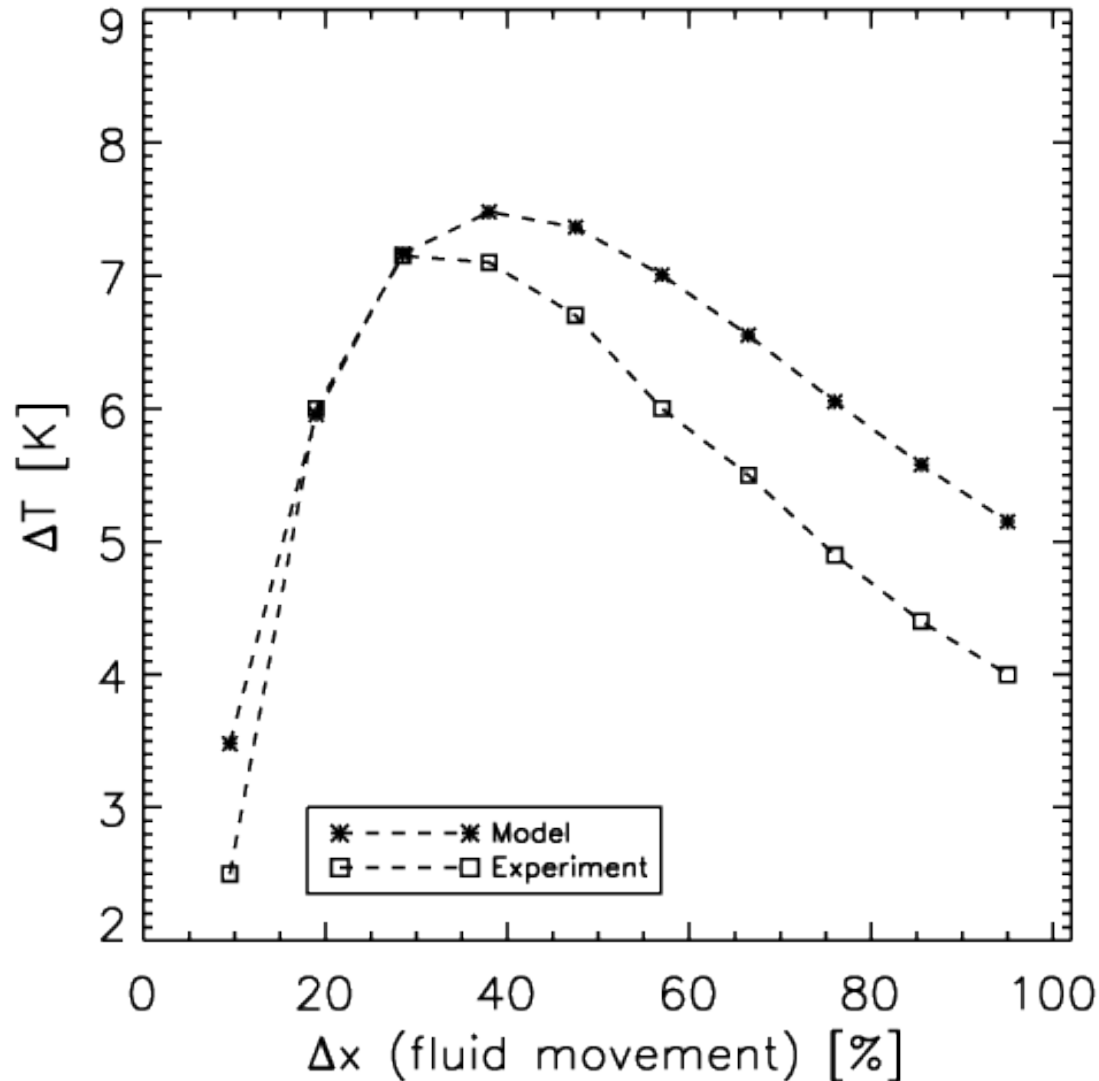
Each experiment was configured as follows

- 13 plates of commercial grade Gd (92 g)
- Plate thickness: 0.9 mm
- Channel thickness: 0.8 mm
- A cycle timing of 9 s

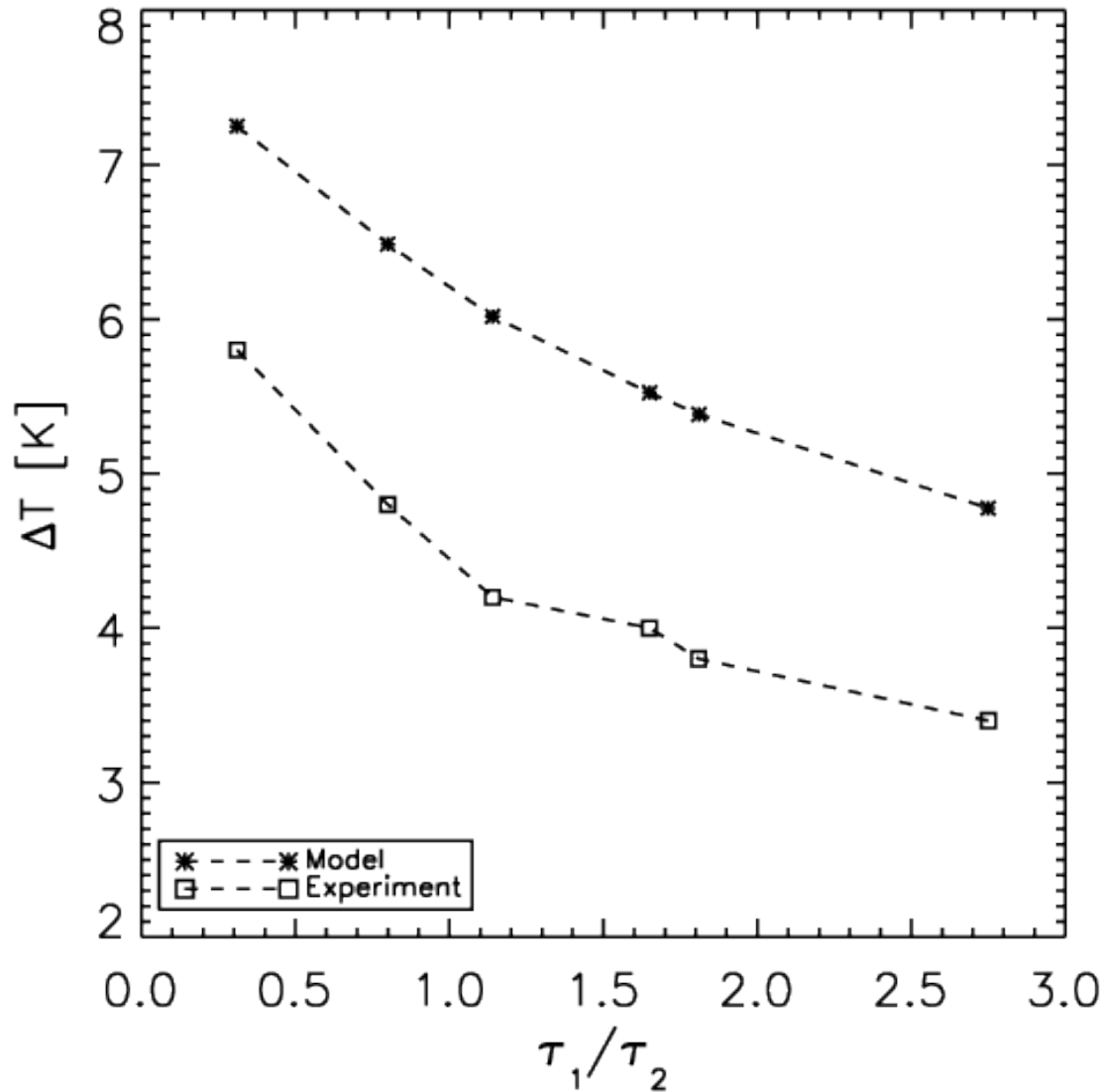
Heat load results



Fluid movement results



Timing results



Summary and Conclusion

- A versatile experimental AMR was presented
- A corresponding advanced 2.5D numerical model was described
- Selected results from experiment and model were compared and to a certain extent the agreement is satisfactory

Future work

- Further development of the model to include e.g. passive regeneration and composite materials
- Present large range of experiments with corresponding modeling of various materials
- Detailed study of demagnetization effects
- Work on composite materials

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