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"A 2D Computational Model of an Active Magnetocaloric Regenerator with Parallel Plates"

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Agenda

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Introduction

Modern cooling devices

→ Based on vapor compression technology

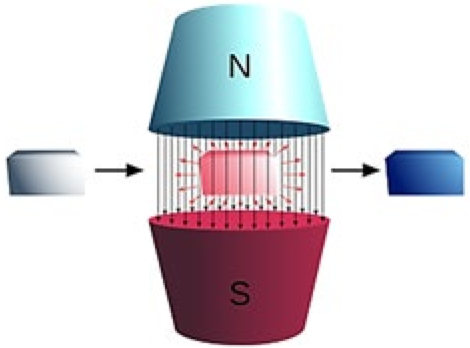
→ High greenhouse effect potential
Low energy efficiency

Environmental-friendly alternative

→ Magnetic Refrigeration

→ Zero ozone depletion and global warming potential
High efficiency and low energy consumption

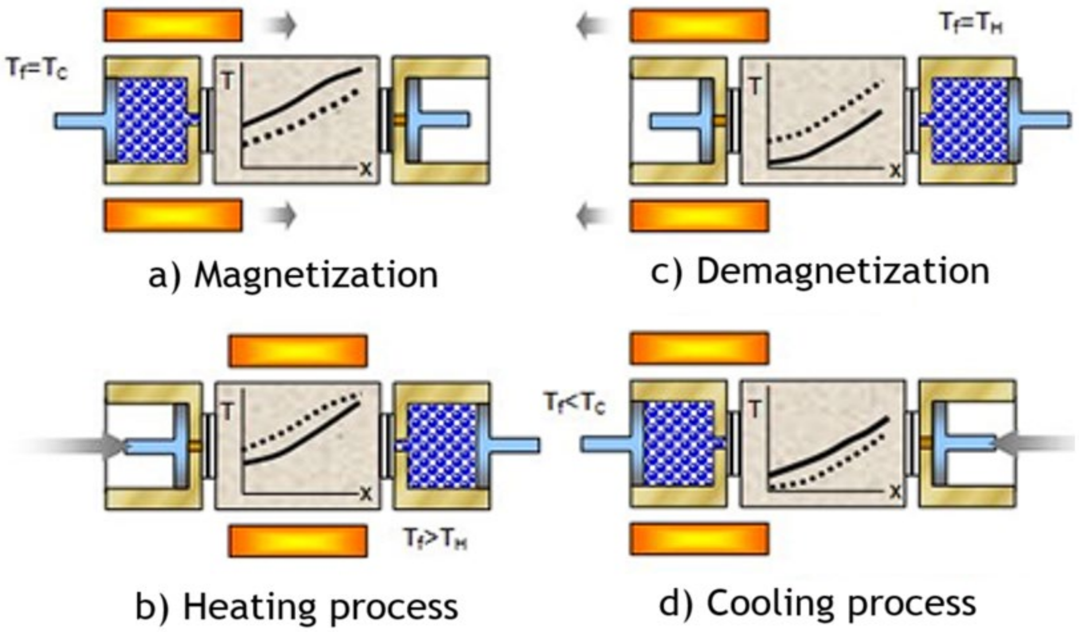
→ Based on the magnetocaloric effect (MCE)



Introduction

This work aims to study the performance of three different MCMs – Ni49.6Mn34.2In16.1, and Ni50Mn35In15 Heusler compounds, and Gd – in an AMR with parallel plates using a robust computational model developed in COMSOL Multiphysics®

AMR principle, Brayton refrigeration cycle



Solution with COMSOL Multiphysics®. Governing Equations

Navier-Stokes momentum and continuity equations for incompressible fluids

$$\rho_f \left(\frac{\partial U}{\partial t} + (U \cdot \nabla) U \right) - \mu_f \nabla^2 U + \nabla p = 0$$

$$\nabla \cdot U = 0$$

Energy-balance relations for heat transfer in solids and fluids

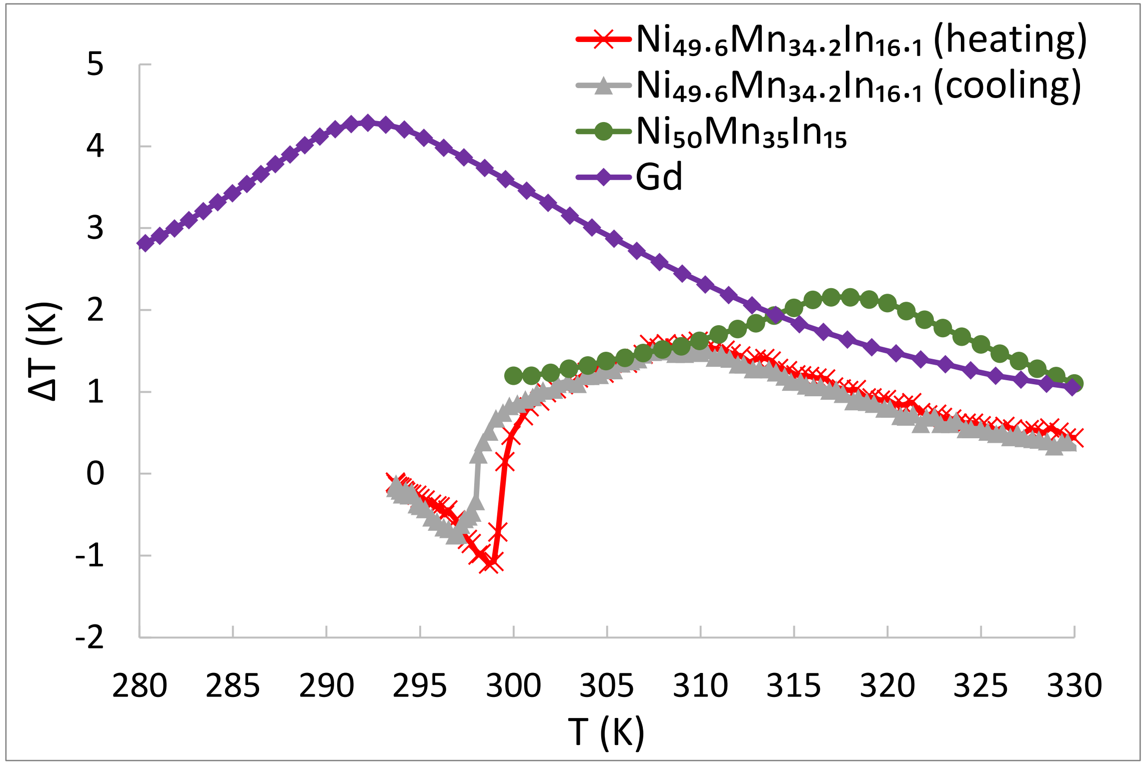
$$\rho_s c_{p,s} \frac{\partial T_s}{\partial t} - k_s \nabla^2 T_s = \dot{Q}_{MCE} + \dot{Q}_{HT}$$

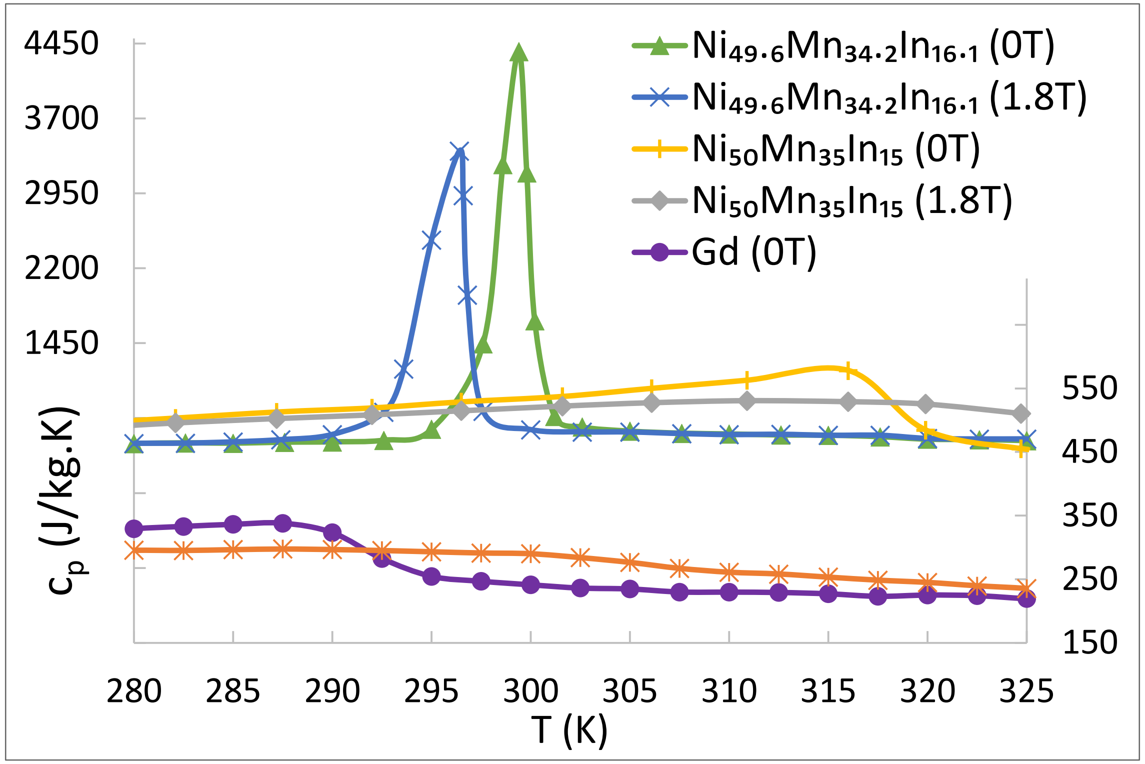
$$\rho_f c_{p,f} \left(\frac{\partial T_f}{\partial t} + (U \cdot \nabla) T_f \right) - k_f \nabla^2 T_f = -\dot{Q}_{HT}$$

Solution with COMSOL Multiphysics®. MCE inclusion

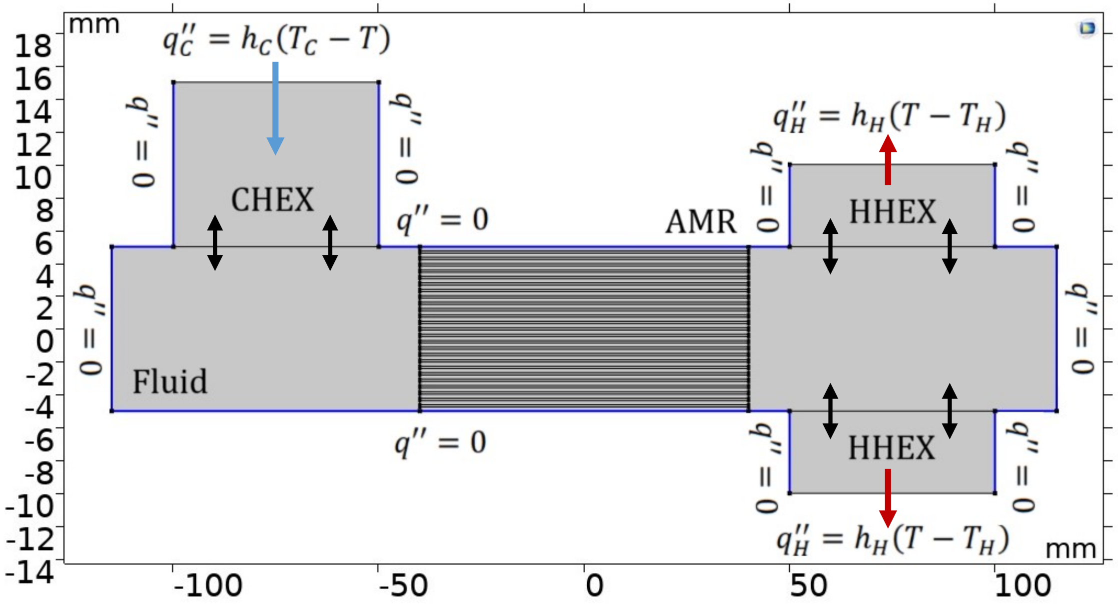
Magnetocaloric effect added as a heat source in the energy-balance equation

$$\rho_s c_p(H,T)\frac{\Delta T_{ad}(H,T)}{dt} = \dot{Q}_{MCE}$$





Solution with COMSOL Multiphysics®. AMR modeling



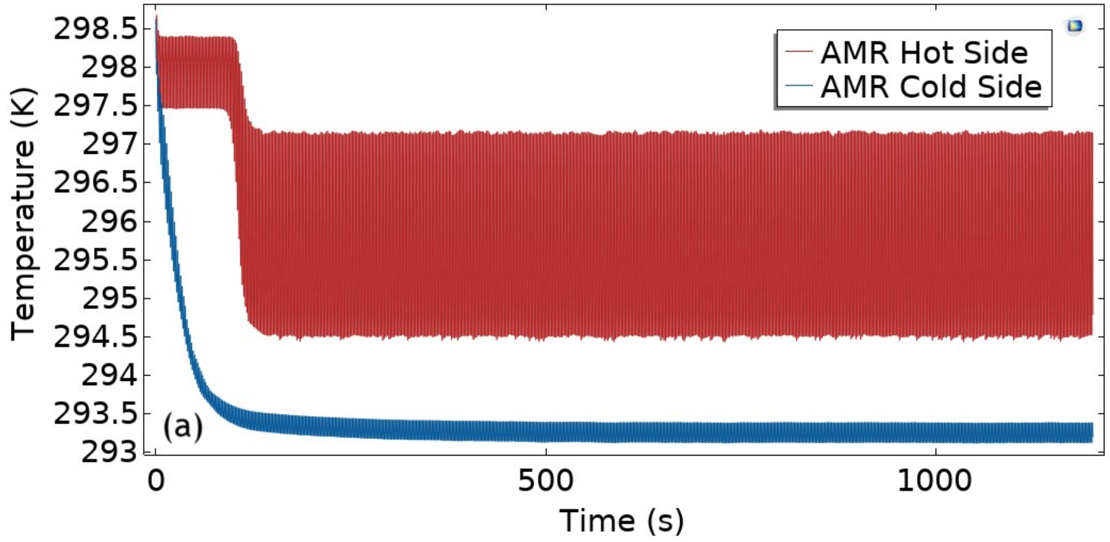
Magnetic Device geometry and boundary conditions

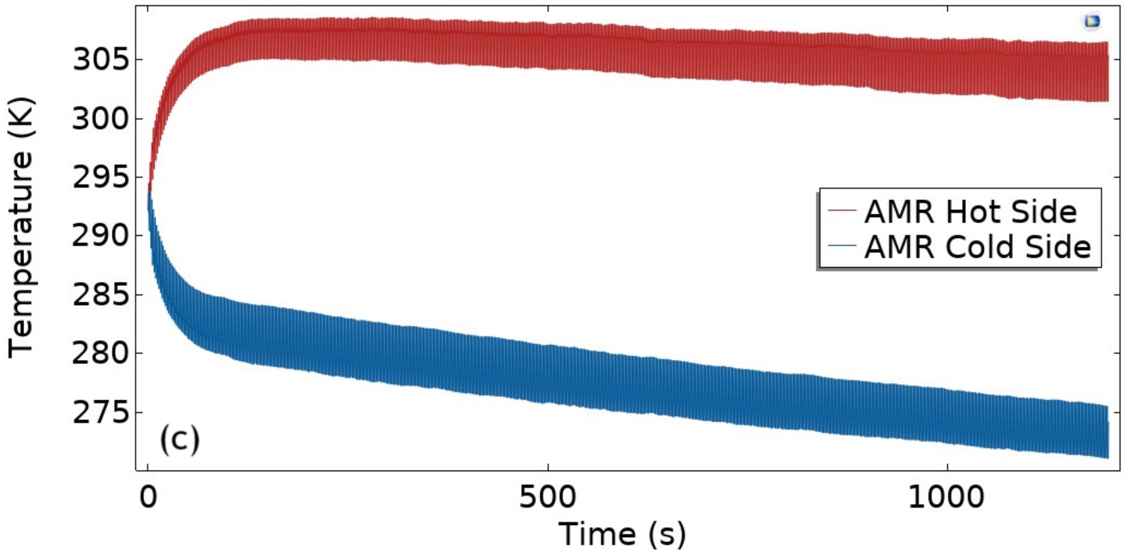
$$\left(k_f \frac{\partial T_f}{\partial y}\right)\Bigg|_{y=H_{fl}} = \left(k_s \frac{\partial T_s}{\partial y}\right)\Bigg|_{y=H_{fl}}$$

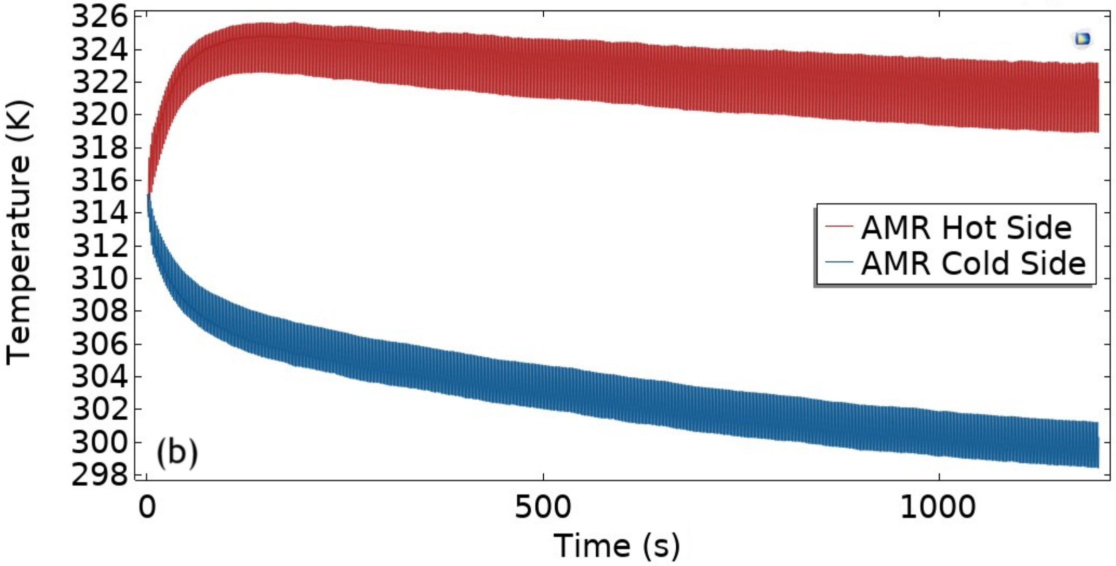
Initial Conditions and working parameters

Parameter	**Value**
Magnetic field strength	1.8T
Total cycle period	2s
Fluid flows step time	1s
(de)magnetization step time	1s
Fluid velocity	0.024 m/s
Heat flux CHEX (h_C)	0 W/(m^2.K)
Heat flux HHEX (h_H)	10E3 W/(m^2.K)
$Ni_{49.6}Mn_{34.2}In_{16.1}$ initial temperature	298K
$Ni_{50}Mn_{35}In_{15}$ initial temperature	316K
Gd initial temperature	292K

Results and discussion



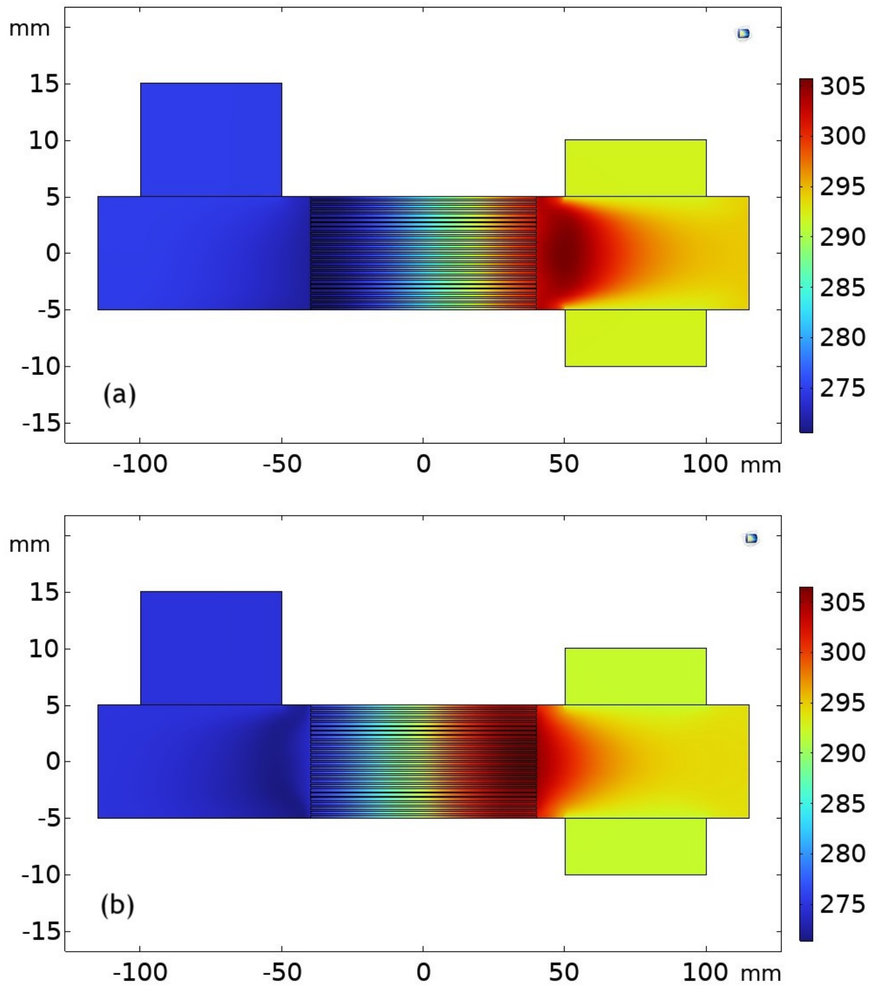




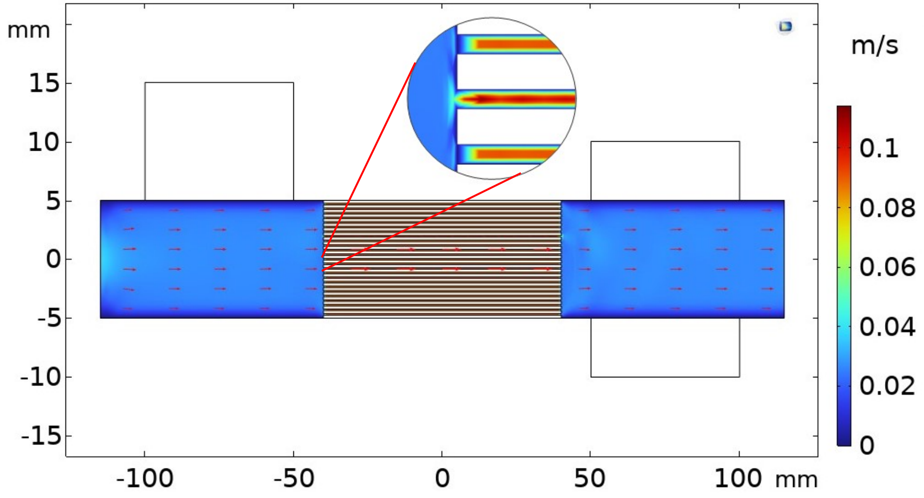
ΔT behavior over time at the hot and cold ends of the AMR for

(a) $Ni_{49.6}Mn_{34.2}In_{16.1}$
(b) $Ni_{50}Mn_{35}In_{15}$
(c) Gd

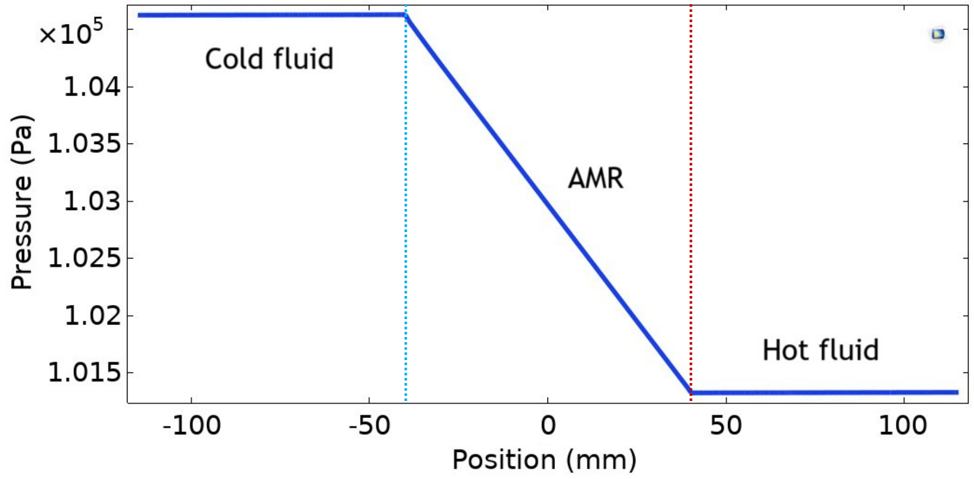
Results and discussion



Temperature gradient across the AMR during
(a) hot blow
(b) cold blow



Velocity profile along the cooling device



Pressure losses across the AMR

Results and discussion

Performance metrics for all MCMs

Parameter	Value
$Ni_{49.6}Mn_{34.2}In_{16.1}$	
Temperature span	4.5K
Cooling capacity	151.05W
Coefficient of performance	-1.05
$Ni_{50}Mn_{35}In_{15}$	
Temperature span	14.89K
Cooling capacity	847.81W
Coefficient of performance	1.80
Gadolinium	
Temperature span	17.25K
Cooling capacity	974.78W
Coefficient of performance	0.79

Temperature span

$$\Delta T_{span} = T_{HHEX} - T_{CHEX}$$

Cooling capacity

$$q'_c = \int_0^{\tau} \int_0^{L_{HEX}} q''_c \, dxdt$$

Coefficient of performance (COP)

$$COP = -\frac{q'_c}{w'_{tot}}$$

$$w'_{tot} = q'_r + q'_c + \frac{U_f \nabla p}{\eta_{pump}}$$

Conclusions

- The performance of three magnetocaloric materials has been evaluated in terms of temperature span, cooling capacity and coefficient of performance using a robust AMR 2D-model with parallel plates.
- The Gd performs better than the other two Heusler compounds but followed closely by $Ni_{50}Mn_{35}In_{15}$, while the $Ni_{49.6}Mn_{34.2}In_{16.1}$ has undesirable behavior also displaying the lowest values for the metrics mentioned.
- $Ni_{50}Mn_{35}In_{15}$ Heusler compound is viable option with great cost effectiveness, but for cooling applications working above room temperature – around 316K.
- The computational results obtained with Comsol Multiphysics® are encouraging for future studies where certain parameters of the model can be varied to optimize the response of the MCMs and the cooling device.

Acknowledgments

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