femto-st
SCIENCES & TECHNOLOGIES

Multiphysics modelling of magnetocaloric device and experimental results

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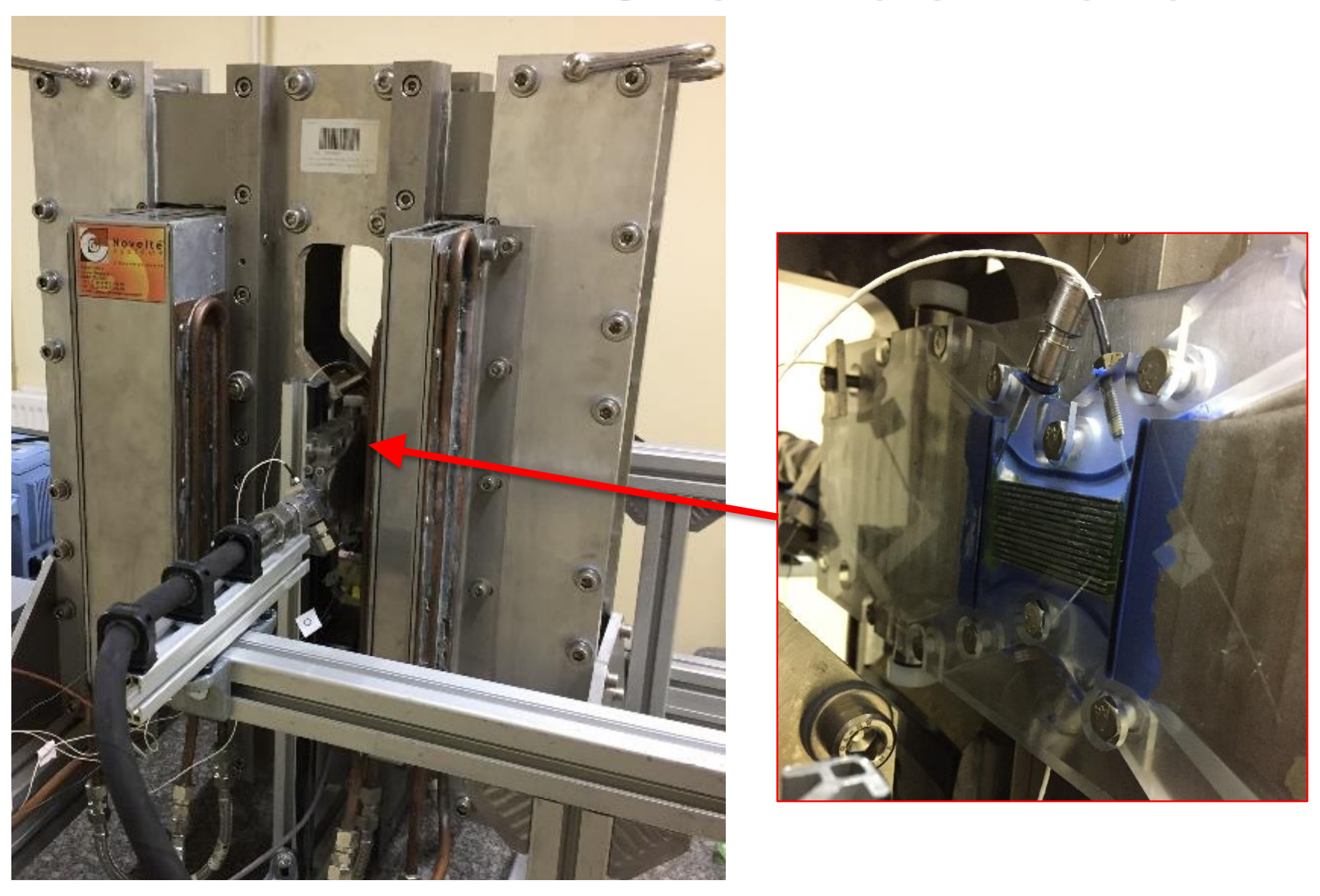
Context and objectives

❑ AMR cycle analysis

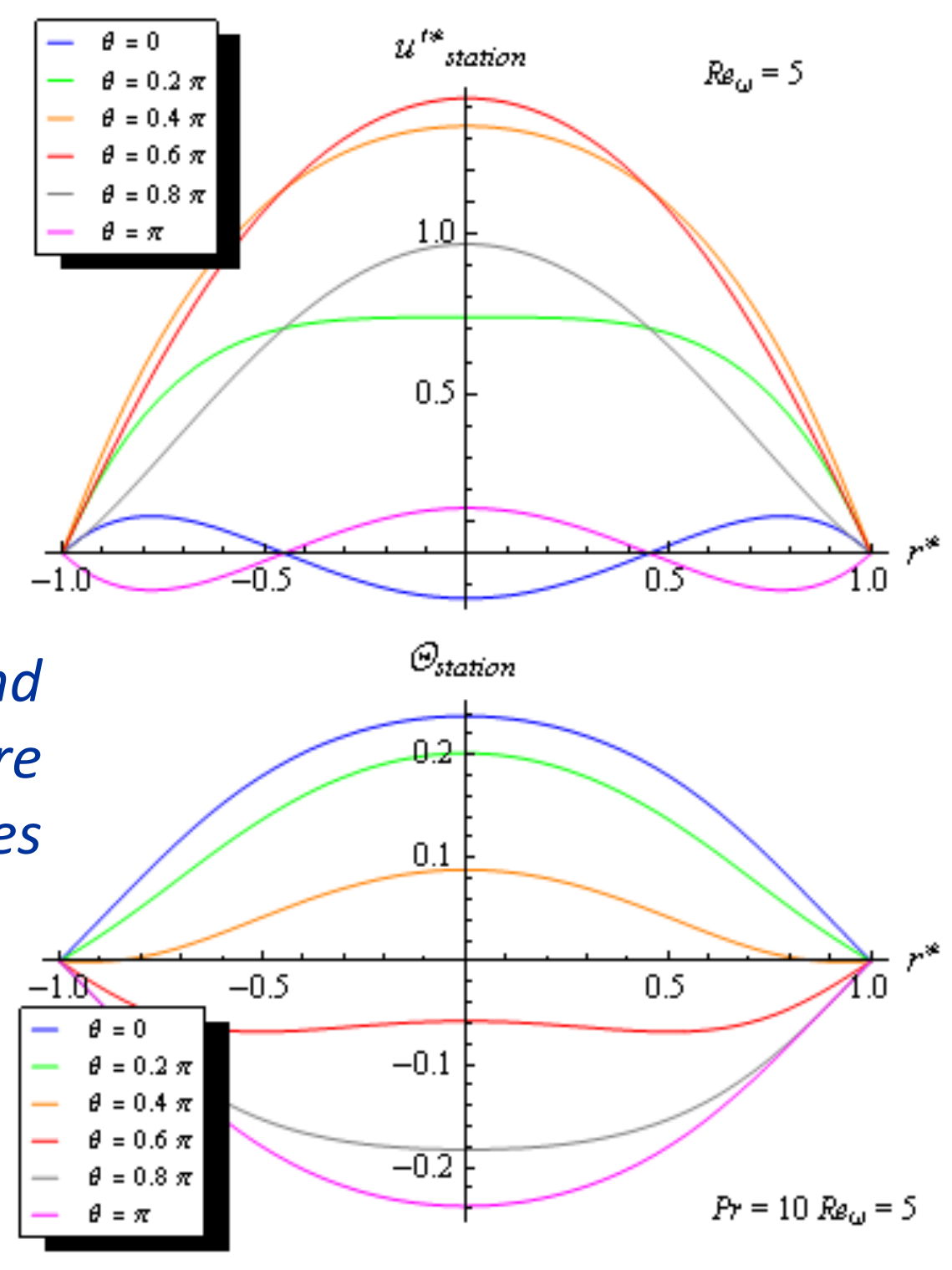
- ➢ Designing, implementing, optimizing devices for cheaper heating and refrigeration devices based on the magnetocaloric effect



FEMTO-ST magnetocaloric device

❑ Physical study of magnetocaloric regenerators

- ➢ Modelling all phenomena that occur in magnetocaloric regenerator with alternating flow of coolant between parallel plates during AMR cycles



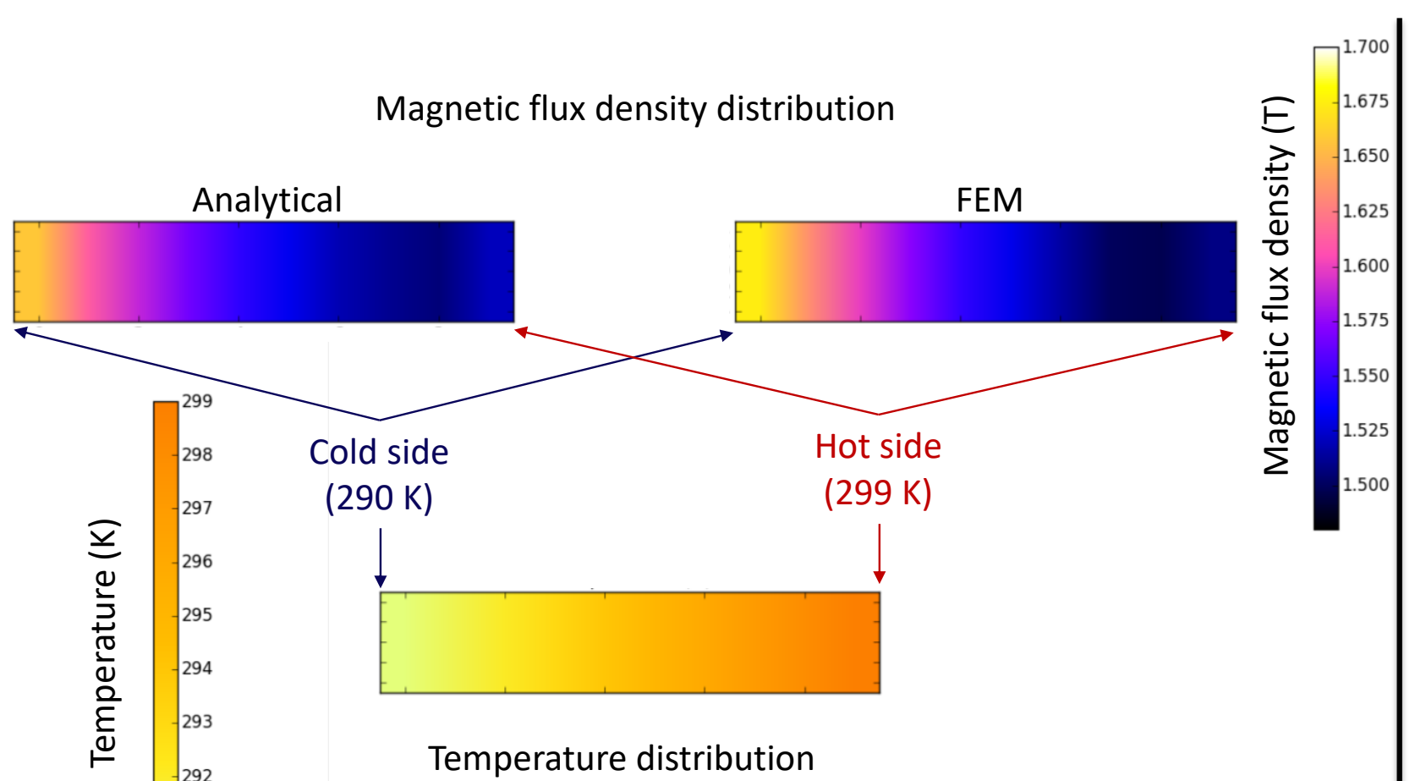
Velocity and temperature profiles

Multiphysics modelling

❑ Magnetostatic model

- ➢ *2D modeling of the internal magnetic field and magnetic flux density distribution in magnetocaloric material*

→ Magn. Equiv. Circuit (reluctance network)
→ B_{int} and H_{int} for every node
→ calculation time = FEM calculation time/300

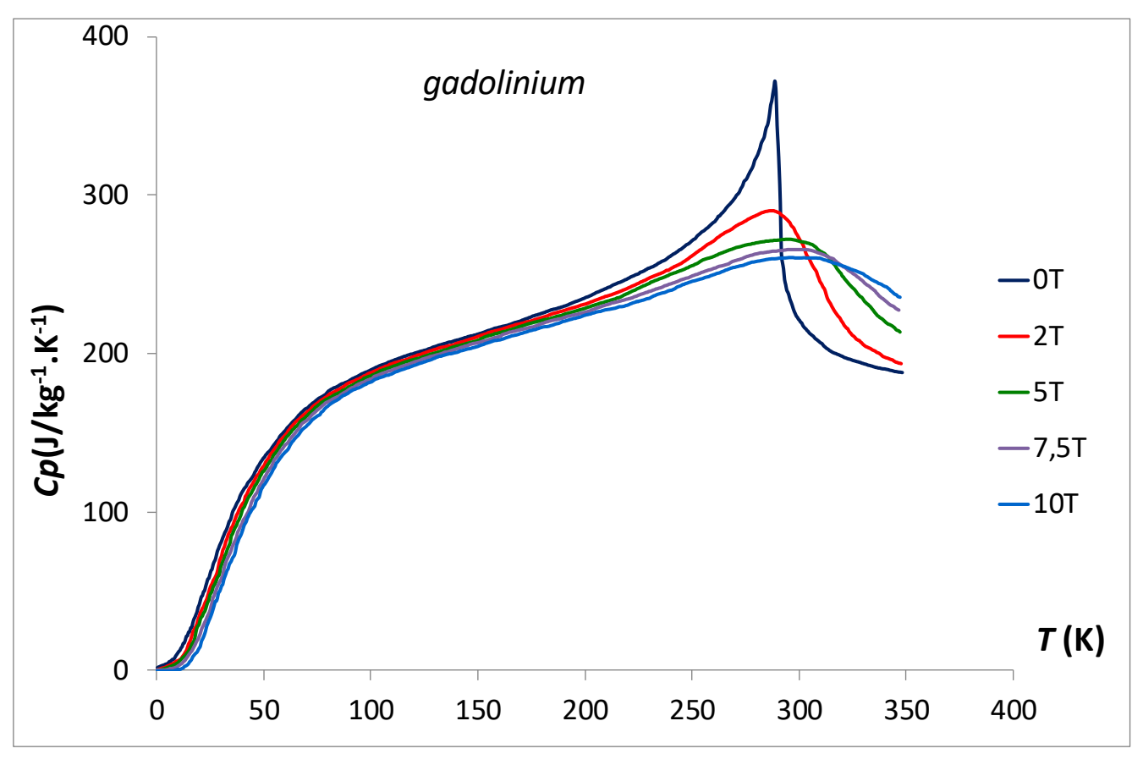


gadolinium plate
(left end : 290 K ; right end : 299 K)

❑ Magnetocaloric model

- ➢ *2D modeling of thermodynamic of ferromagnetic transient, with magnetization distribution and magnetocaloric power density generate*

→ magnetization $M(H_{int}, T)$ behavior
→ magnetocaloric power density $\dot{q}$



$$\dot{q} = -\mu_0 T \left(\frac{\partial M}{\partial T}\right)_{H_{int}} \frac{dH_{int}}{dt}$$

❑ Thermo-fluidic model

- ➢ *2D modeling of heat transfers of magnetocaloric material (parallel plates) with oscillating flow*

→ heat capacity (interpolate experimental data)
→ solid temperature
→ fluid temperature

$$\frac{\partial T_s}{\partial t} = \frac{\lambda_s}{\rho_s C_s}\left(\frac{\partial^2 T_s}{\partial x^2} + \frac{\partial^2 T_s}{\partial r^2}\right)$$

$$\frac{\partial T_f}{\partial t} + u\frac{\partial T_f}{\partial x} = \frac{\nu}{Pr}\left(\frac{\partial^2 T_f}{\partial x^2} + \frac{\partial^2 T_f}{\partial r^2}\right)$$

❑ CFD model (Fluent©) :

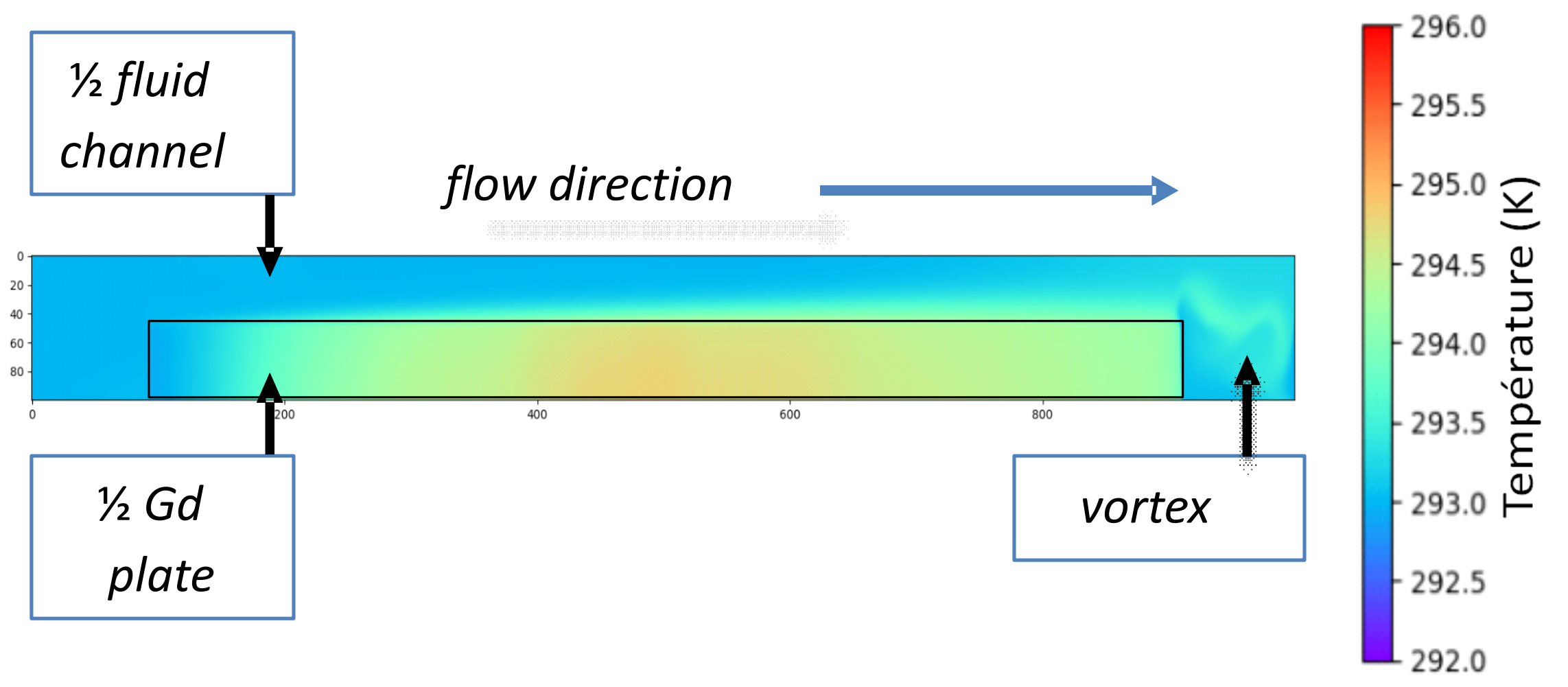
- ➢ *2D and 3D modeling of heat transfers of magnetocaloric material (parallel plates) with oscillating flow*

➔ numerical reference for magnetocaloric numerical simulations in Python code

→ material : gadolinium
→ geometry : parallel-plate
symmetry simplification : ½ plate and ½ canal
→ frequency : any value
→ method : temperature jump / source term
→ *Cp* : constant / *T* & *B* dependent
→ demagnetizing field : with / without
→ sinusoidal flow / trapezoidal flow

Objectives:

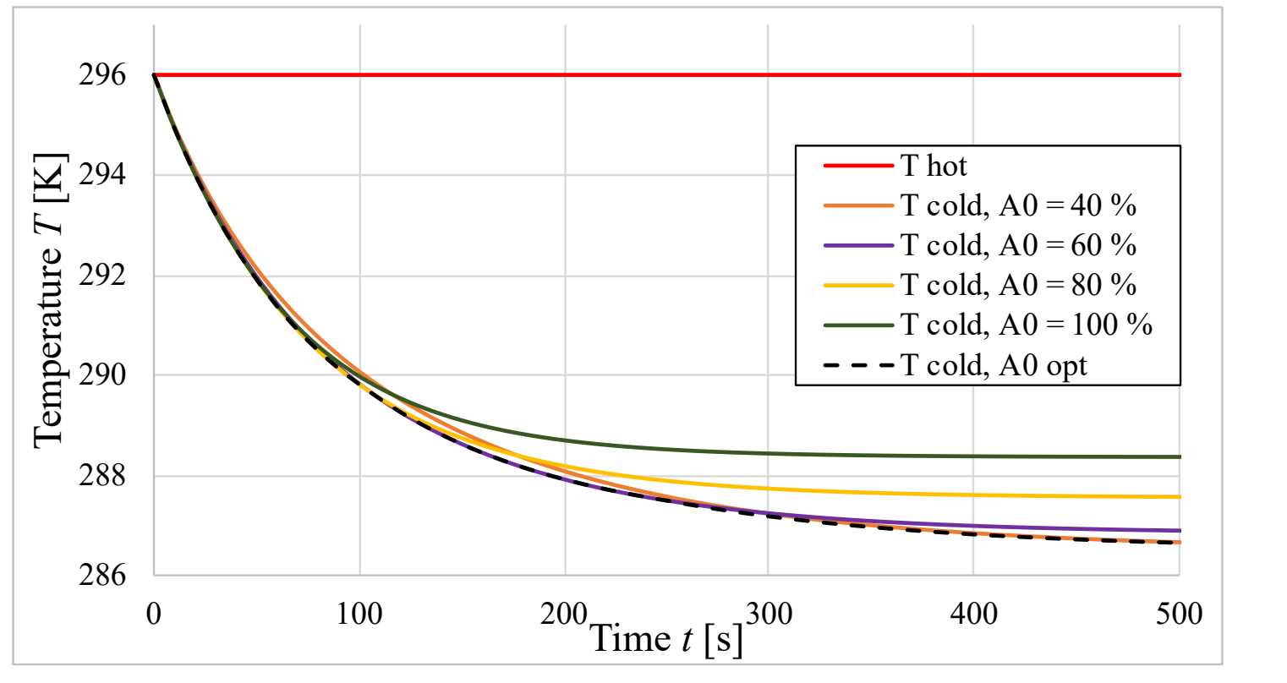
- annular effect
- effect of plate micro-structuration on AMR efficiency
- simulation of multi-Curie regenerator for optimization of the AMR efficiency



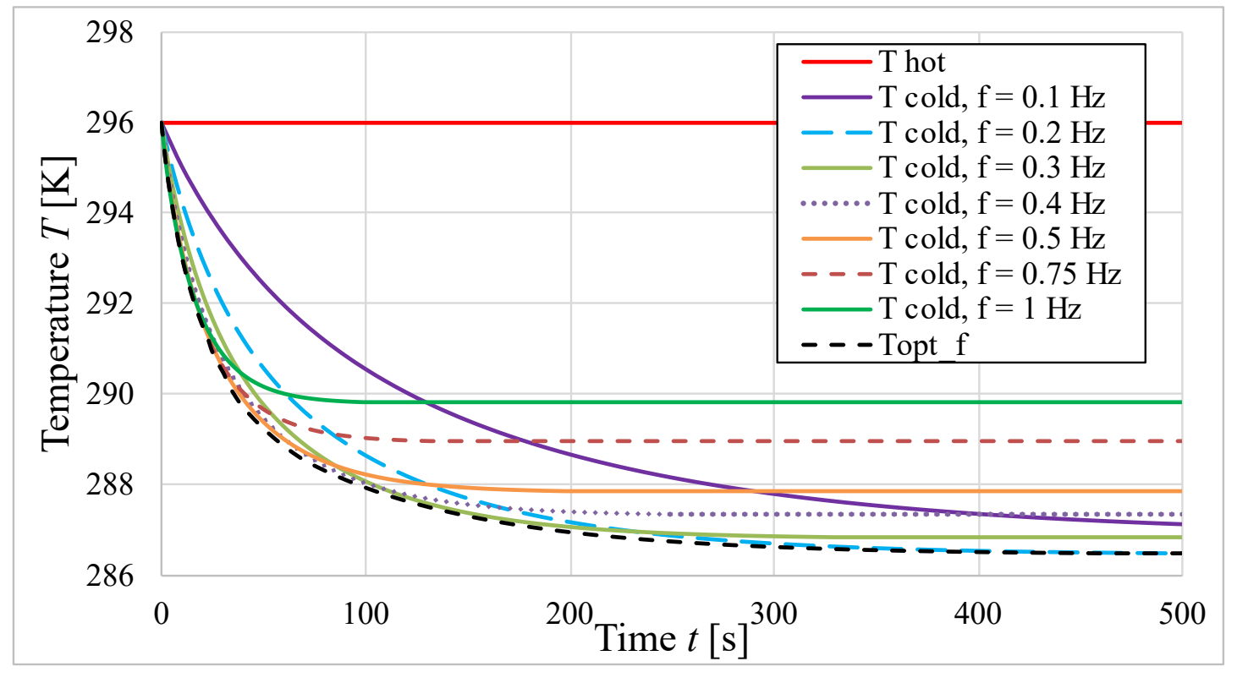
Results, comparison and optimization

❑ Simulation results

- ➢ *Imposed hot side temperature 296 K ; free cold side temperature (code Python)*

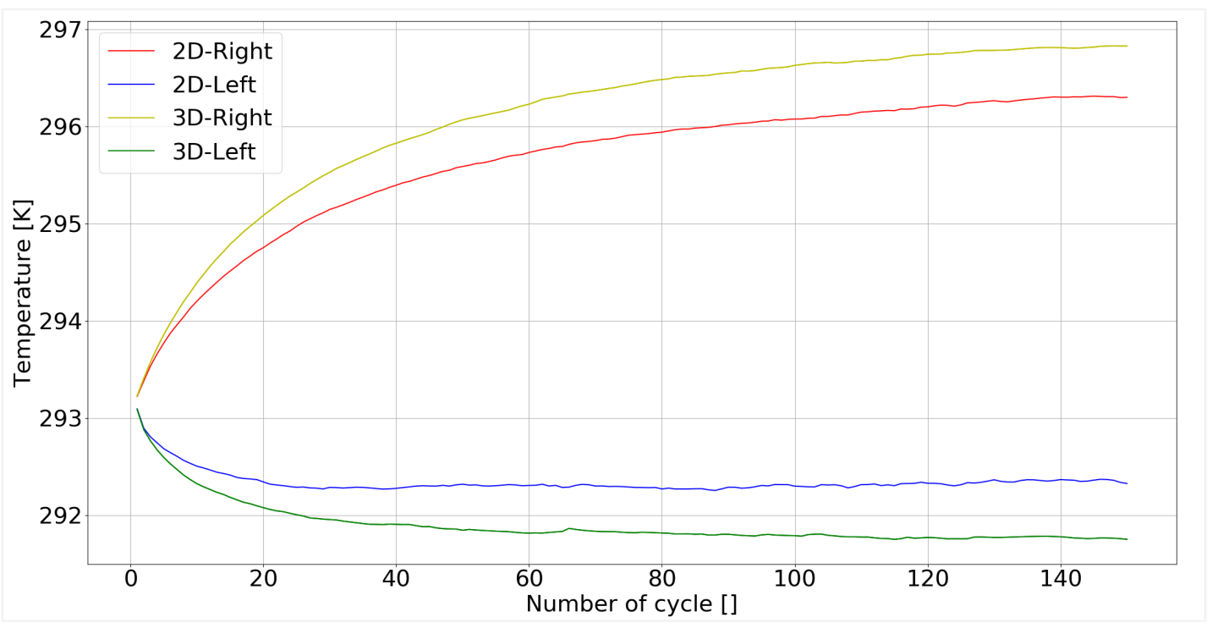


Influence of fluid displacement ratio A_0

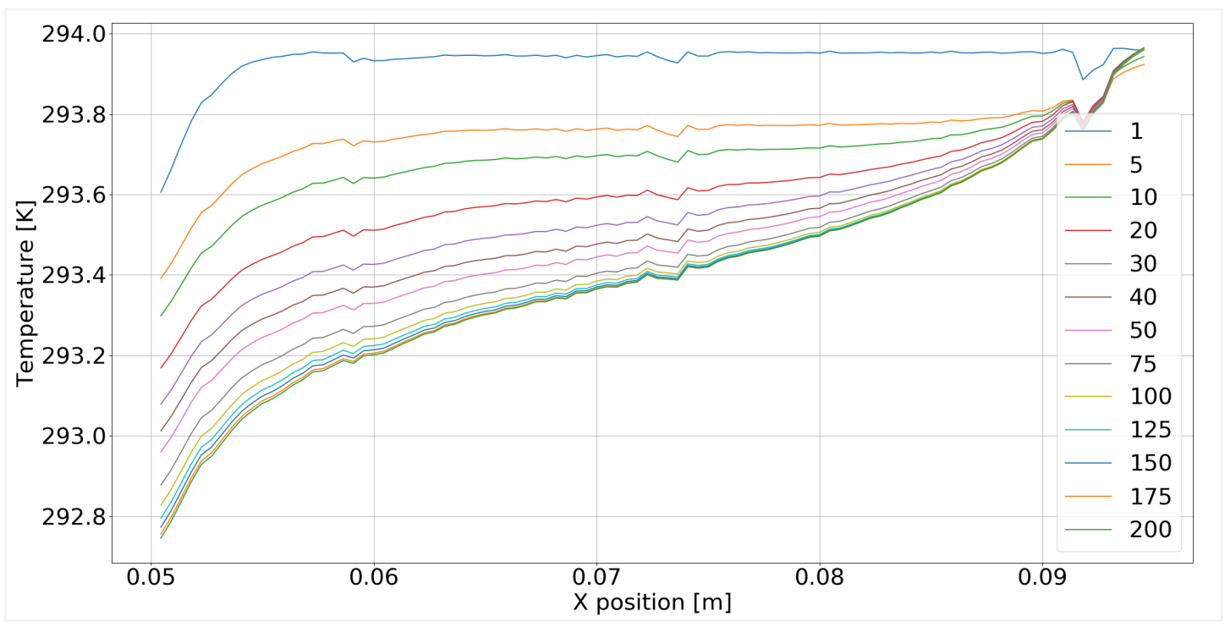


Influence of frequency f

- ➢ *Adiabatic case (Fluent)*



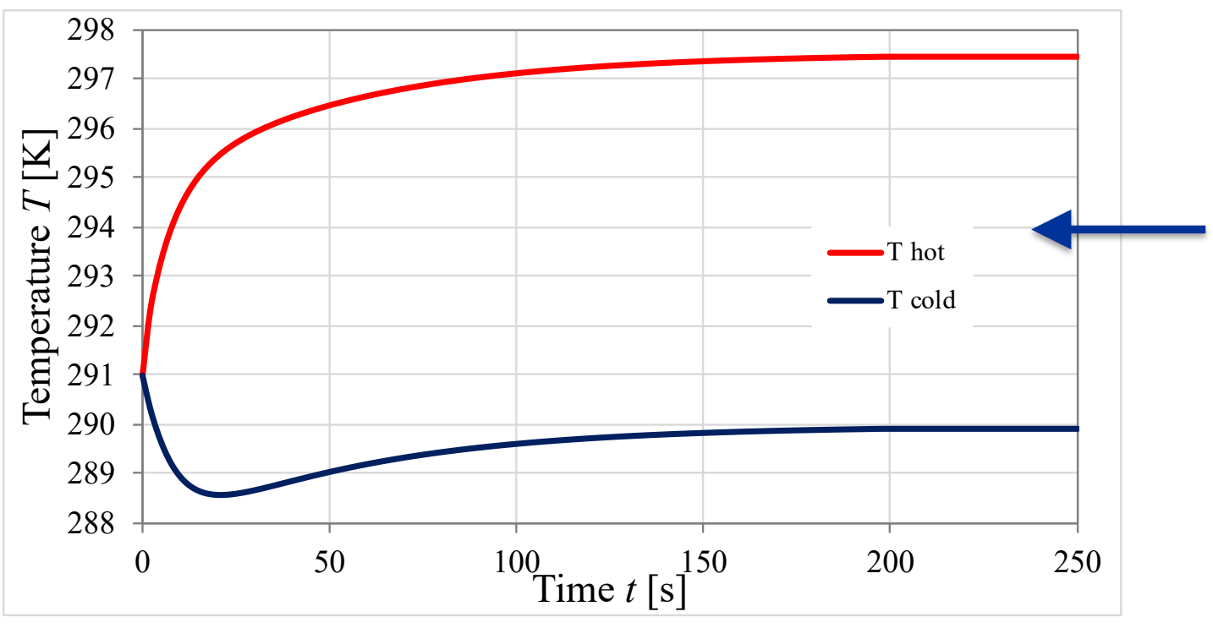
Gadolinium plate temperatures for 2D and 3D simulation (adiabatic case)



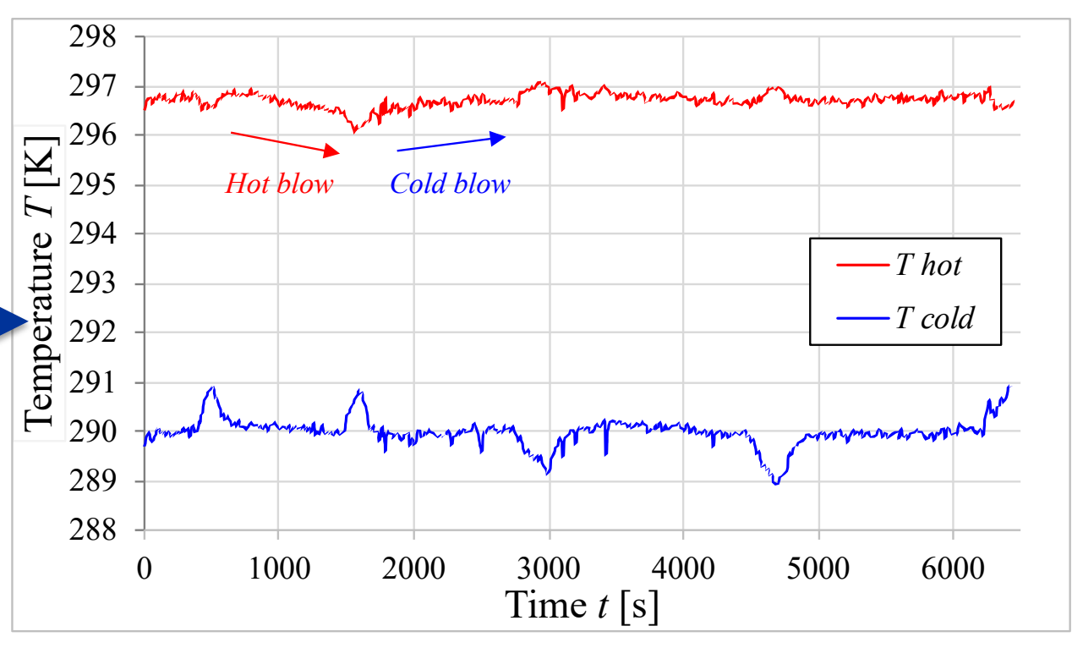
Axial temperature profile evolution over AMR cycles (adiabatic case)

❑ Experimental results

- ➢ *Temperature evolution (f = 0,5 Hz, A_0 = 56%) in adiabatic conditions*



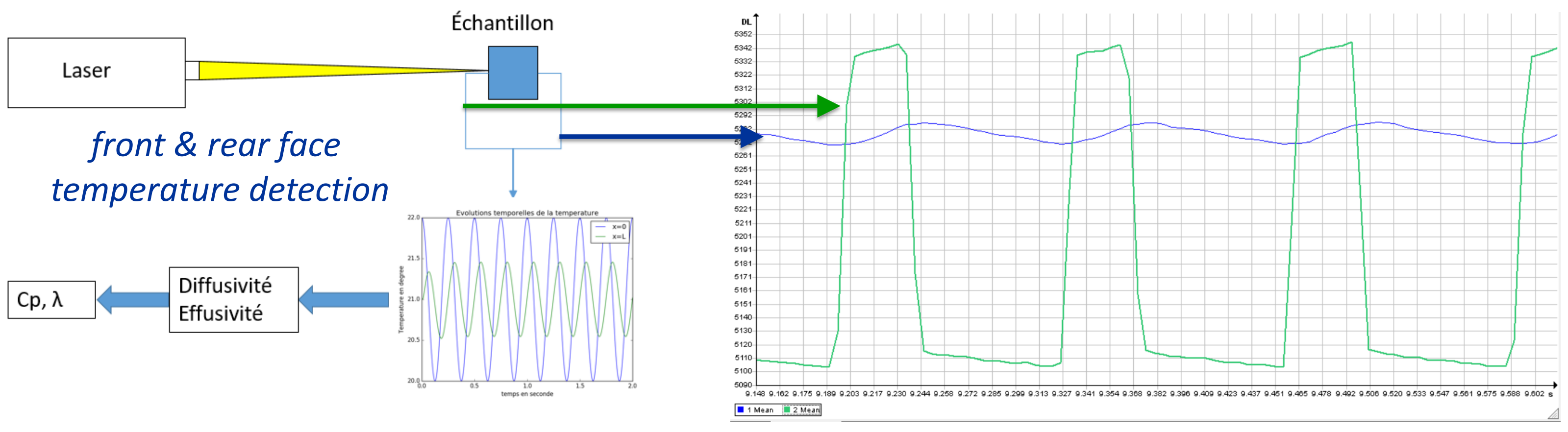
comparison MPM simulation/ experiment



Gadolinium regenerator temperature
(multiphysics simulation → 7,6 K)

Temperature results at steady
(experimental bench → 6,9 K)

- ➢ *Thermo-flash calorimetry of magnetocaloric materials in magnetic field*



front & rear face temperature detection

Conclusions and prospects

❑ Key points

- *very fast time calculation of multiphysics modelling compared to FEM codes*
- *high physical reliability of regenerator behavior in AMR cycles*
- *avoiding heat transfer, friction or porosity coefficients*
- *optimization of frequency and fluid displacement ratio for accelerated refrigeration*
- *good fit between multiphysics modelling and experimental results*

❑ Further modelling and experiments

- *extended calculations and experiments to high frequency* → annular effect
- *multi-Curie temperature regenerators* → higher MC power density
- *µ-PIV investigation of alternating flow in magnetocaloric regenerators*
- *high precision measurement of Cp(H,T) and λ(H,T) of magnetocaloric materials*
- *CompoMag Project for new optimized magnetocaloric composite regenerators*

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