Experimental validation of 2D-Multiphysics numerical simulations applied to long time AMR cycles

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Abstract

The Energy Department of the FEMTO-ST Institute is developing large theoretical and experimental research on high efficiency magnetocaloric refrigeration for several years. The analysis of the active magnetic regenerative (AMR) cycles for different waveforms of both the magnetic field and the fluid velocity is an essential tool for designing and implementing efficient heating and cooling applications based on the magnetocaloric effect.

Our laboratory developed first a powerful electromagnet as magnetic source composed of four coils winded on a soft ferromagnetic eight-shaped yoke, which induces 1 T magnetic field short pulses inside a 21 mm air gap. The fluidic device is a hydraulic cylinder producing precise flow sequences through a specific Plexiglas® case housing a built-in magnetocaloric regenerator and two 316L steel micro-heat exchangers. This module is inserted and positioned at the air gap center. The magnetocaloric regenerator consists of 14 pure gadolinium plates, spaced 0.5 mm apart, through which Zitrec™ flows as a cooling fluid.

The waveform of both the magnetic field and the fluid velocity is an important control means for obtaining optimum results (temperature gap, cooling power, etc.). For this purpose, a Hall effect sensor is glued on one polar piece of the electromagnet, and a magnetic position transductor measures the instantaneous piston displacement of the hydraulic device. Precise control and synchronization of both the applied magnetic field and the fluid flow are obtained by choosing operating frequencies as well as fluid displacement ratios in a LabVIEW™ parametric controlled regulation and monitoring program. Besides, in order to investigate the phenomena occurring in the regenerator, thermocouples and pressures sensors are immersed in the fluid at both ends of the regenerator and the two micro-heat exchangers (Figure).

The modelling of the multi-physics phenomena inside the active magnetocaloric regenerator requires the coupling of magnetostatic (Plait et al, (2019)), magnetocaloric and thermo-fluidic models. The 2-D semi-analytical multi-physics model calculates also the internal magnetic field and magnetic flux density (magnetostatic phenomena), magnetization and magnetocaloric power density (magnetocaloric phenomena), heat capacity, temperature and velocity (thermo-fluidic model).

The evolution of the temperatures on the both sides of the regenerator obtained experimentally is compared with the numerical simulations for different control parameters. For example, the Figure presents a comparison between experimental measurements and simulation results for a frequency 0.5 Hz and a fluid displacement ratio (A_0) 56 %. The fluid temperature span at steady state between two tanks (Figure) is around 6.9 K, in adequation with the numerical results (7.4 K).

Different operation cases are studied and shown in the Table. The different fluid temperature spans between the hot and cold tanks are obtained for different fluid displacement ratios at constant cycle frequency (0.5 Hz). Experimental and simulated results are in good agreement as exposed in the Table. These first experimental results provide a good validation of the developed 2-D semi-analytical multiphysics model. More explanation of the multiphysics model and the experimental device is given in (Plait et al (2021)).

Keywords: Magnetic refrigeration, magnetocaloric device, experimental results, theoretical results.

Key Results

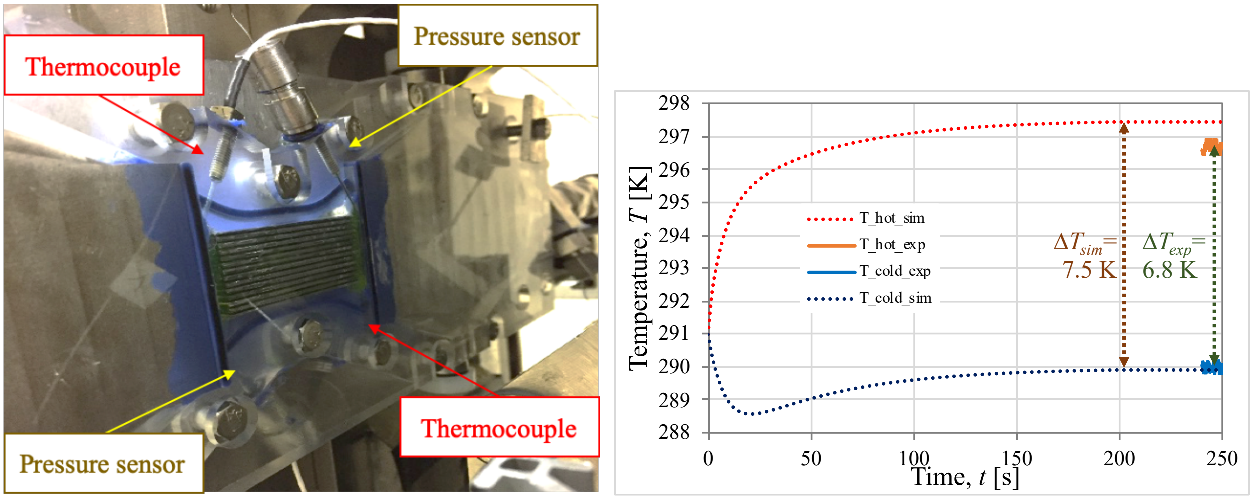

Figure: Experimental regenerator (left); experiment-simulation comparison at f = 0.5 Hz, A_0 = 56 % at steady state (right)

Table: Comparison between experimental and 2-D semi-analytical results

Case description	ΔT experimental (K)	ΔT simulated (K)	Error (%)
f = 0.5 Hz, A_0 = 56 % after 150 AMR cycles	3.9	4.2	7
f = 0.5 Hz, A_0 = 56 % at steady state	6.8	7.5	9
f = 0.5 Hz, A_0 = 67 % at steady state	5.8	6.1	4.9

References:

Plait, A., Giurgea, S., de Larochelambert, T., Nika, P., Espanet, C., 2018. Low computational cost semi-analytical magnetostatic model for magneto-caloric refrigeration systems, AIP adv. 8, 095204.

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