Reduction of transient refrigeration time by modulation of fluid displacement ratio and operating frequency of a magnetocaloric device

Antony Plait, Stefan Giurgea, Thierry de Larochelambert, Christophe Espanet

FEMTO-ST Institute, CNRS, Univ. Bourgogne Franche-Comté, Belfort, 90000, France
antony.plait@gmail.com

Abstract

In the literature, there are a lot of one-dimensional magnetic refrigeration model developed using less or more well adapted exchange coefficients. In order to reduce assumptions and approximations, a global two-dimensional (2-D) multiphysics model has been developed for an AMRR magnetocaloric device. It integrates successively:

- a magnetostatic model based on a semi-analytical modeling of the magnetostatic phenomena, which takes into account the nonlinear behaviour of the ferromagnetic external circuit as well as the active magnetocaloric material (MCM) properties. The analytical model calculates the values of the internal magnetic field and the internal magnetic flux density at each point of the regenerator volume;
- a magnetocaloric model for calculating the magnetic power density produced in the magnetocaloric material as a result of the magnetic field variation (provided by the magnetostatic model), combined with the interpolation of the local magnetization of the magnetocaloric material (from experimental data) as a function of local magnetic field and temperature values;
- a thermo-fluidic model, which solves the energy and momentum equations using an implicit finite-difference method. It also calculates the heat capacity and the thermal conductivity of the magnetocaloric material as a function of temperature and internal magnetic field, allowing to update the new temperatures of both the fluid and the material.

The capacities and performances of the 2-D multiphysics model (Plait et al. (2021)) are studied by the influence of input parameters on the temperature difference and the time necessary to obtain the steady state in adiabatic mode.

The first study consists in calculating the influence of the two main operating parameters – the fluid displacement ratio A_0 and the AMR frequency f – in order to obtain the maximal temperature difference between the two ends of the regenerator. The fluid displacement ratio ranges from 5 % to 100 % of the channel volume for every specific operating frequency between 0.1 Hz and 1 Hz. The first figure shows the maximal temperature mapping obtained at steady state and permits to observe a maximal span temperature of 16 K, with a combination $\{A_0, f\}$ = {25 %, 0.3 Hz}. However, some other combinations permit to obtain a similar temperature difference (in equipotential zones combining whether lower A_0 with higher f or combination of higher A_0 with lower f). This kind of study was realized in the literature (Bahl et al. (2008), Almanza et al. (2015)), which permits to validate this study. Thus, it is interesting to identify which combination permits to reduce the time necessary to obtain these results.

For that, the second study consists in calculating the transient temperature between the start and the stationary regime, allowing to determine the best combination $\{A_0, f\}$, which ensures the fastest cooling rate. The second figure shows the mapping of the time necessary to achieve the steady state. A high frequency combined to a high fluid displacement ratio permits to reduce the time necessary to obtain the steady state. In our configuration the best combination to obtain the maximal temperature difference in a minimal time is {20 %, 0.5 Hz}.

Keywords: Magnetic refrigeration, multiphysics model, temperature difference, operating frequency, fluid displacement ratio.

Key Results

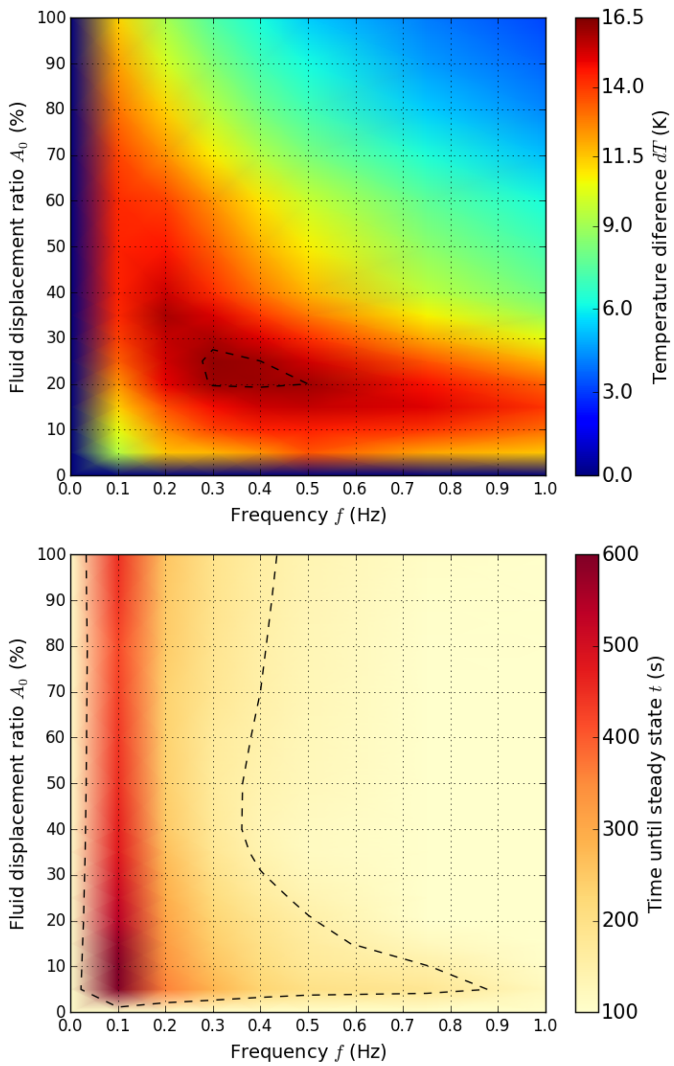

Figure: Mapping of temperature difference (top); time necessary to obtain steady state (bottom)

References:

Plait, A., de Larochelambert, T., Giurgea, S., Espanet, C., 2021. Validation of a Multiphysics modelling of AMR cycles in a magnetocaloric bench. Int. J. Refrigeration, Submitted.

Bahl, C., Petersen, T.F., Pryds, N., and Smith, A., 2008. A versatile magnetic refrigeration test device. The Review of scientific instruments, 79(9), 093906.

Almanza, M., Kedous-Lebouc, A., Yonnet, J.P., Legait, U., and Roudaut, J., 2015. Magnetic refrigeration: recent developments and alternative configurations. European Physical Journal: Applied Physics, EDP Sciences, 71 (1), pp.10903.