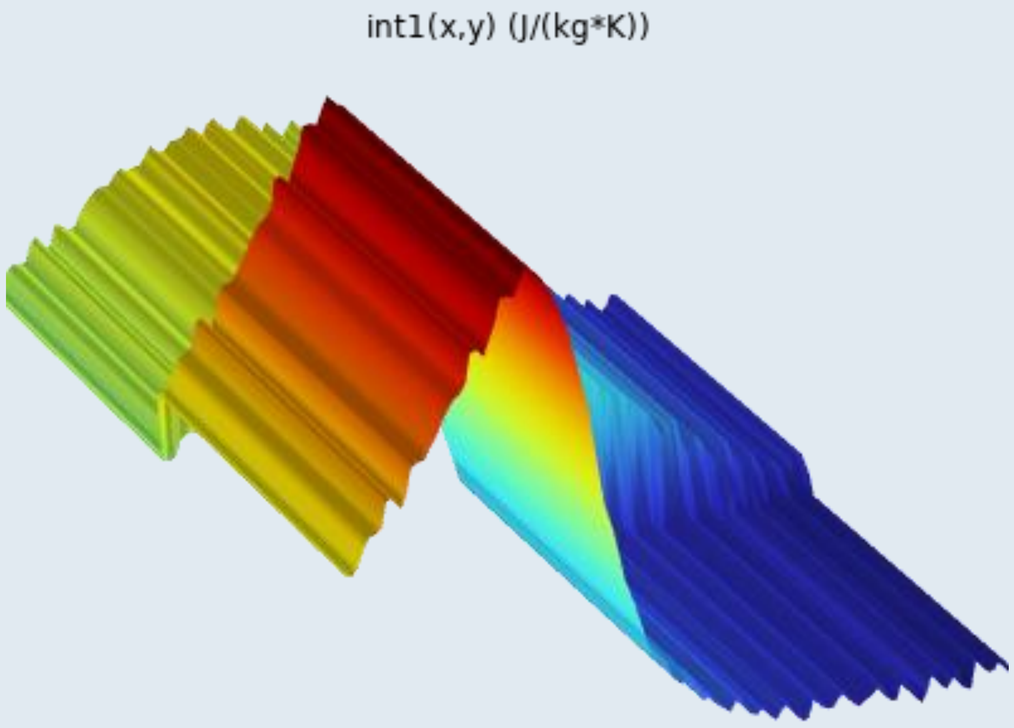

A 2D Computational Model of a Packed-Bed Magnetic Refrigeration System

A 2D time-dependent model of a magnetic refrigeration system with a porous AMR is developed. The magneto-caloric effect of the magnetic material is introduced by interpolated functions based on experimental data of Gd.

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Introduction

In this work we use COMSOL Multiphysics® 6.2 to develop a two-dimensional time-dependent model of a magnetic refrigeration system with an active magnetic regenerator (AMR) [1], simulating a magnetocaloric device. The physical model consists of an AMR configured as a porous packed-bed of Gd spheres [2], two heat exchangers for the hot and cold environments, and a working fluid [3]. ΔT_{ad} and heat capacity of the material are measured experimentally rather than mean field approximations. Main metrics used to evaluate the magnetic device performance are the maximum temperature span obtained, the cooling capacity at no-load condition, and the coefficient of performance (COP). The study takes into consideration free and porous media flow and conjugated heat transfer mechanisms in the system. Then, an uncertainty quantification study is carried out to identify the most influential input parameters for the AMR temperature span. The results yield that gadolinium offers moderate cooling capability and extended temperature span, but low COP.

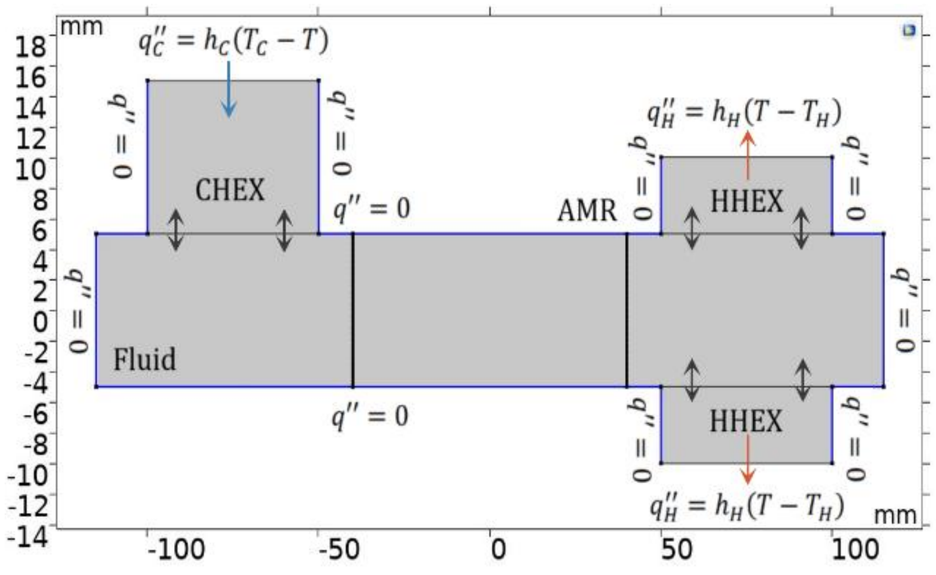

Figure 1. AMR model and boundary conditions used.

Methodology

The model is based on the COMSOL Multiphysics® Heat Transfer Module and CFD Module, coupling the Heat Transfer in Solids and Fluids with the Free and Porous Media Flow physics under the Non-Isothermal Flow Multiphysics interface. The dependent variables, such as fluid pressure and velocity, and temperature distribution across the AMR, are solved using the FEM. The velocity and pressure profiles are determined along the fluid and used to compute the temperature distribution in both the solid and fluid domains during the cold and hot blows. The process is repeated for several cooling cycles for the system to reach a steady-state condition. Then, the assessment of the performance of the system is determined by the temperature span achieved for the device, its cooling capacity, and COP. Finally, an uncertainty quantification study is carried out.

Results

We have developed a 2-dimensional, time-dependent AMR model of a packed bed with Gd spheres with an experimentally based MCE source term. The model has been used to quantify device-level performance and parameter sensitivities under a 1.8 T, 2s Brayton-like cycle. The simulations have delivered a temperature span across the heat exchangers of 16.83K, a cooling capacity of 1274.69W, and COP = 1.41 at no-load, with a pressure drop of ~34.45kPa and mean blow velocity near 0.025m/s, values consistent with a reliable regeneration but noticeable hydraulic losses. An uncertainty quantification study has shown that displaced volume and frequency are the most influential parameters, but with a non-negligible porosity contribution. Additionally, it has been computed a modest risk (~3%) of failing a 37.5 K regenerator-end temperature span threshold used for internal diagnostics.

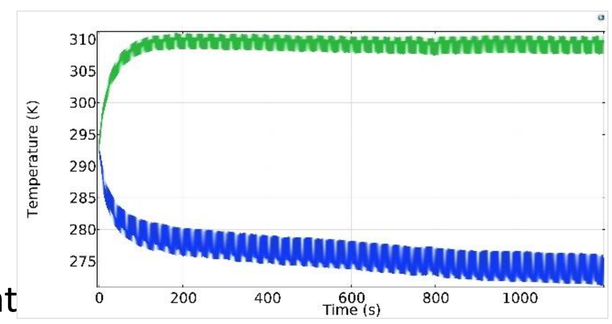

Figure 2. ΔT behavior over time at the hot and cold ends of the porous AMR.

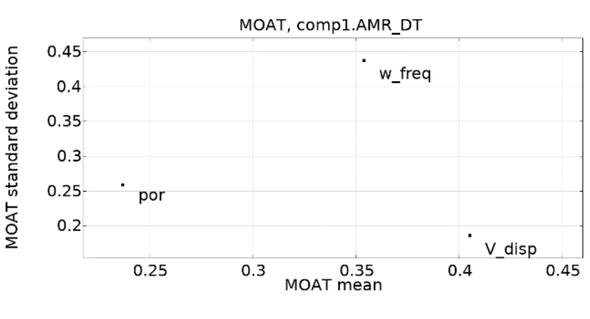

Figure 3. MOAT plot from screening study, indicating general effect on x-axis and nonlinearity on y-axis.

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