A 2D Computational Model Of A Packed-Bed Magnetic Refrigeration System

Bruno Chinè[1], Francisco Rodríguez-Méndez[2], Marcela Meneses-Guzmán[3], Simone Fabbrici[4], Franca Albertini[5]

[1]School of Materials Science and Engineering, Costa Rica Institute of Technology, Cartago, Costa Rica, bchine@itcr.ac.cr
[2]School of Materials Science and Engineering, Costa Rica Institute of Technology, Cartago, Costa Rica, frarodriguez@itcr.ac.cr
[3]School of Industrial Production Engineering, Costa Rica Institute of Technology, Cartago, Costa Rica, mameneses@itcr.ac.cr
[4]Institute of Materials for Electronics and Magnetism, National Research Council, Parma, Italy, simone.fabbrici@cnr.it
[5]Institute of Materials for Electronics and Magnetism, National Research Council, Parma, Italy, franca.albertini@imem.cnr.it

Abstract

Among the different uses of primary energy in the industrial and residential sectors, refrigeration and air conditioning systems consume around 17% of the electricity produced worldwide [1], reaching dissipated powers of approximately 2000 TWh [2]. These devices are based on the vapor-compression method that uses fluorocarbons and carbon dioxides with the ability to deplete the ozone layer by contributing 7.8% to greenhouse gas emissions [3] [4], also demonstrating poor energy efficiency [5]. In the other hand, magnetic refrigeration is considered an environmentally friendly and sustainable alternative since it uses a solid material with magnetocaloric properties as a refrigerant and heat exchanger element, which exhibits zero ozone depletion and global warming potential. Moreover, it also has a range of excellent features, such as a compact configuration, low noise, high efficiency, good stability and longevity [6], singularities that significantly impact the cost, energy consumption, and feasibility of the system.

In this work, a two-dimensional time-dependent model of a magnetic refrigeration system with an active magnetic regenerator (AMR) is developed to simulate a magnetocaloric device. The physical model consists of an AMR configured as a porous packed bed of spheres, two heat exchangers for the hot and cold environments, and a working fluid. The cyclic flow is described by the Brinkman equations for porous media, meanwhile the Local Thermal Nonequilibrium frame accounts for the heat transfer in the liquid, solid and porous domains. The coupling between these physics is added by using the COMSOL Multiphysics® Conjugate Heat Transfer option that combines the Heat Transfer in Solids and Fluids [7] and the Porous Media Flow [8] modules under the Non-Isothermal Flow Multiphysics interface. Then, the magnetocaloric effect is introduced by the inclusion of a source term in the energy equation that is dependent on the adiabatic temperature change and the specific heat of the magnetocaloric material. The latter two parameters are inserted into the model by using interpolated functions based on experimental magnetic behavior data for gadolinium (known for being the benchmark material, but with high criticality and low availability) and Ni50Mn35In15 Heusler compound (highly available and non-critical).

Several time-dependent studies are carried out using the uncertainty quantification tools of COMSOL Multiphysics® [9], varying the working frequency, fluid velocity and the packed-bed porosity, aiming to optimize the device's response in terms of performance, cooling capacity and temperature span reached. The results yield that the gadolinium offers better cooling capability and extended temperature span, but lower COP (Coefficient of Performance) if compared with the Ni50Mn35In15 alloy, under the same initial conditions, showing the potential of this Heusler compound for future magnetic refrigeration systems.

Reference

[1] D. Coulomb et al., "The Role of Refrigeration in the Global Economy," 29th Informatory Note on Refrigeration Technologies, Technical Report, International Institute of Refrigeration, Paris, France, 2015.
[2] International Energy Agency, "The Future of Cooling," 2018. [Online]. Available: http://www.iea.org/reports/the-future-of-cooling. [Accessed July 2023].
[3] D. Coulomb et al., "The Impact of the Refrigeration Sector on Climate Change," 35th Informatory Note on Refrigeration Technologies, Technical Report, International Institute of Refrigeration, Paris, France, 2016.
[4] Y. Hwang, "Harmonization of the Life Cycle Climate Performance Methodology," 32nd Informatory Note on Refrigeration Technologies, International Institute of Refrigeration, Paris, France, 2016.
[5] H. Ucar et al., "Using numerical methods to screen magnetocaloric materials in an active magnetic regenerative cycle," International Journal of Refrigeration, vol. 120, pp. 50-57, 2020.
[6] B. Yu et al., "A review of magnetic refrigerator and heat pump prototypes built before the year 2010," International Journal of Refrigeration, vol. 33, pp. 1029-1060, 2010.
[7] Comsol AB, Comsol Multiphysics-Heat Transfer Module, User's Guide, Version 6.2, 2023
[8] Comsol AB, Comsol Multiphysics-CFD Module, User's Guide, Version 6.2, 2023.
[9] Comsol AB, Comsol Multiphysics-Uncertainty Quantification Module, User's Guide, Version 6.2, 2023.

Figures used in the abstract

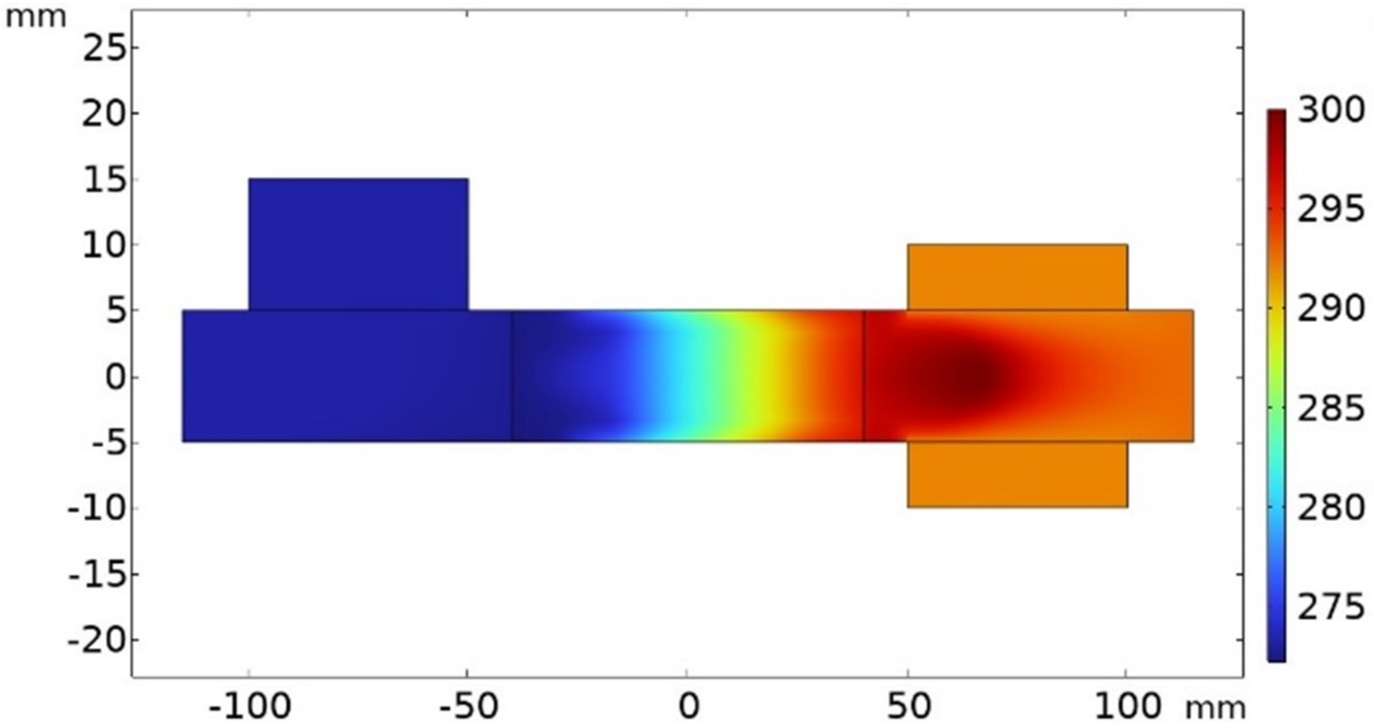

Figure 1 : Temperature regeneration profile produced for the Gadolinium at the steady-state phase.