Modeling of a Magnetocaloric System for Electric Vehicles

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Abstract

Introduction
In automotive industry, regardless the type of engine we use, heating and air-conditioning is responsible for the highest energy consumption among all the auxiliary systems all over the year.

For conventional vehicles with thermal engines, the heating of the internal space is easy obtainable because of the heat waste from the engine. For the electric vehicles, as the energy is delivered by the batteries, the power consumption for heating as well as for air-conditioning can imply a significant reduction of the vehicle's autonomy.

This paper presents some aspects of the design of an innovative magnetocaloric system used for the construction of an efficient HVAC unit for electric vehicles, which is an alternative to traditional HVAC systems based on gas compression.

Magnetocaloric HVAC system has higher energy efficiency than the classical gas compression system and also the advantage that it does not use greenhouse gas or other pollutants as classical HVAC does. Magnetocaloric technology is based on the magnetocaloric effect which consists in the variation of the internal energy of magnetocaloric materials as the result of the magnetic field variation.

The main part of this system is the magnetocaloric regenerator presented in the Figure 1.

Magnetocaloric regenerator is composed of several thin parallel plates, alternating with mini-channels containing circulating heat transfer fluid.

The numerical simulation of the behaviour of the magnetocaloric regenerator is needed in order to study the best ways for optimizing the system efficiency, in particular, the heat transfer coefficient and the thermodynamic cycle.

Use of COMSOL Multiphysics®
The complete simulation of the specific magnetocaloric cycle named active magnetic regenerator refrigeration cycle takes into consideration more than one type of physics. COMSOL Multiphysics® makes it possible to couple them together in a simple and intuitive way. The complete model is governed by the equations in Figure 2: Continuity equation (1),

Momentum equations (2), Energy equation (3), and Energy equation governing the heat transfer in the solid (4).

The source term Qmce represents the volumetric heat generation inside the MCM due to the MCE. For a time-dependent model Qmce is described by equation 5 in the figure 2. The principal difficulty of this simulation is the MCE modeling. The problem is solved by using the interpolation function of COMSOL Multiphysics® to interpolate the experimental data of $\Delta T_{ad}(T,\mu_0 H)$ and $C_p(T,\mu_0 H)$, both variables are function of two parameters.

Results
The model described in the previous section allows us to analyse the influence of geometrical parameters and fluid parameters on 'h' coefficient and then on the cycle behaviour. These results are summarized in Figure 3.

Conclusion
This model allows the assessment of the behaviour of the magnetocaloric HVAC in order to improve its design and its driving parameters.

Reference

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Figures used in the abstract

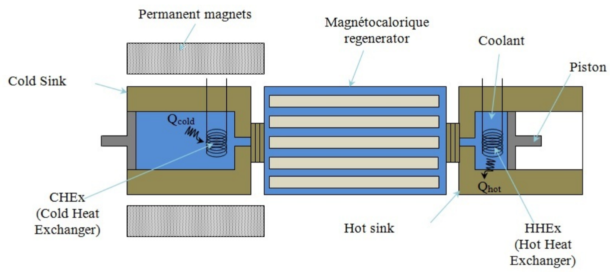

Figure 1: Magnetocaloric system and its components.

$$\nabla \cdot \vec{u} = 0 \tag{1}$$

$$\rho_f (\vec{u} \cdot \nabla)\vec{u} = -\nabla p + \mu_f \nabla^2 \vec{u} \tag{2}$$

$$\rho_f C_{p,f} (\vec{u} \cdot \nabla T_f) = k_f \nabla^2 T_f + h\beta (T_s - T_f)_{Int:f/s} \tag{3}$$

$$k_s \nabla^2 T_s - h\beta (T_s - T_f)_{Int:f/s} + Q_{MCE} = 0 \tag{4}$$

$$\dot{Q}_{MCE} = \rho_s C_{P,s} \left(\frac{\partial T_{ad}}{\partial H} \frac{dH}{dt} + \frac{\partial T_{ad}}{\partial T_s} \frac{dT_s}{dt} \right) \tag{5}$$

Figure 2: Equations governing the physics of a magnetocaloric system

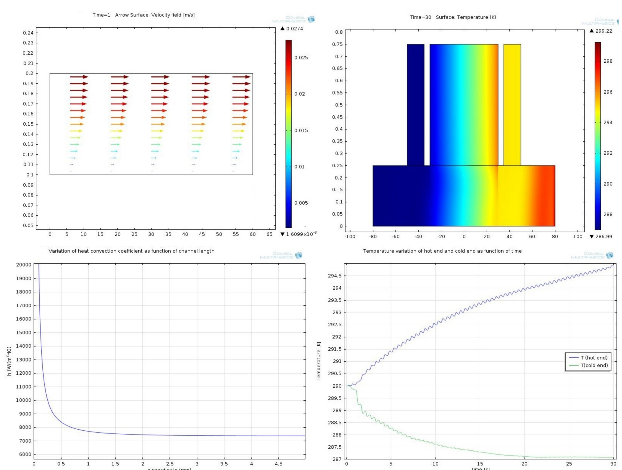

Figure 3: Representation of velocity field, temperature field, variation of heat transfer coefficient, and temperature variation