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# Electrocaloric vs. magnetocaloric energy conversion

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ABSTRACT

Currently, one of the most interesting alternatives to conventional compressor refrigeration is magnetic refrigeration. However, despite its great potential, some important obstacles, relating mostly to the relatively low power density and the related high costs, must be overcome. Another alternative, which also shows great potential, is electrocaloric refrigeration. Until recently, electrocaloric materials were not so common; however, a number of different electrocaloric materials exist today. Like magnetocalorics, these can be used in the form of a regenerator in order to increase the temperature span. Based on a previously developed numerical model, we have made a comparison between electrocaloric and magnetocaloric regenerators. The results suggest that electrocaloric energy conversion represents a serious alternative, not only to compressor-based technologies, but also to magnetocalorics.



# Comparaisons des conversions d'énergie électrocalorique et magnétocalorique

*Mots clés :* Effet électrocalorique ; Effet magnétocalorique ; Froid magnétique ; La conversion de l'énergie ; Réfrigération

## 1. Introduction

There are several different technologies available today to meet the demands for refrigeration and cooling. These demands come from the increased levels of living comfort, as well as from the substantial number of energy sources that we use in our daily lives. Most of the refrigeration or cooling technologies are based on the vapor compression of gas refrigerants. They are characterized not only by a low exergy efficiency (Paul, 2011), but also by the use of environmentally harmful refrigerants. Today's, arguably, most promising alternative, especially for small-scale refrigerators or heat pumps, is magnetic refrigeration (Brown et al., 2010; Brown and Domanski, 2011; Engelbrecht and Bahl, 2010; Tassou et al., 2010). The main drawback of magnetic refrigeration technology, despite its many benefits compared to classical vapor-compressor systems, without ODP and GWP potentials, is the large permanent magnets that are needed to obtain the required changes in magnetic field and therefore the high costs associated with the permanent magnets and with the

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**Nomenclature**

*Symbols*

| | |
|---|---|
| c | specific heat capacity [J K$^{-1}$ m$^{-3}$] |
| COP | coefficient of performance [–] |
| E | electric field [V m$^{-1}$] |
| $\Delta E$ | change in electric field [V m$^{-1}$] |
| H | magnetic field [A m$^{-1}$] |
| $\Delta H$ | change in magnetic field [A m$^{-1}$] |
| M | magnetization [A m$^{-1}$] |
| P | electric polarization [C m$^{-2}$, As m$^{-2}$] |
| Δs | specific entropy change [J K$^{-1}$ kg$^{-1}$] |
| T | temperature [K] |
| ΔT | temperature change [K, °C] |
| $\upsilon^*$ | fluid-displacement ratio [–] |

*Greek*

| | |
|---|---|
| $\lambda$ | thermal conductivity [W m$^{-1}$ K$^{-1}$] |
| $\mu$ | permeability [Vs A$^{-1}$ m$^{-1}$] |
| $\rho$ | density [kg m$^{-3}$] |
| $\psi$ | volume fraction [m$^3$ m$^{-3}$] |

*Indices*

| | |
|---|---|
| ad | adiabatic |
| E | electric field |
| EC | electrocaloric |
| ECM | electrocaloric material |
| eff | effective |
| el | electrode |
| is | isothermal |
| M | magnetic field |
| MC | magnetocaloric |

*Abbreviation*

| | |
|---|---|
| AMR | active magnetic regenerator |
| CHEX | cold heat exchanger |
| GWP | global warming potential |
| HHEX | hot heat exchanger |
| MFA | mean field approximation |
| ODP | ozone depletion potential |

magnetocaloric material itself (mostly based on rare-earth materials).

However, in recent years, another technology has shown great potential, which could help us to produce highly efficient, environmentally friendly and low-cost cooling devices for the future. This technology is referred to as electrocaloric refrigeration (Kutnjak et al., 2011) and could be applied in future air-conditioning, refrigeration, cryogenics, heat-pump and power-generation equipment. The physics of the electrocaloric effect is based on similar principles to the magnetocaloric effect. However, instead of a magnetization–demagnetization process (Eq. (1)), the electrocaloric material undergoes a polarization–depolarization process (Eq. (2)). The result is a positive temperature and a negative entropy change when the external electrical field is applied.

$$\Delta T_{ad,MC} = -\int_{H_1}^{H_2} \frac{T}{c_H}\left(\frac{\partial M}{\partial T}\right)_H dH \quad (1)$$

$$\Delta T_{ad,EC} = -\int_{E_1}^{E_2} \frac{T}{c_E}\left(\frac{\partial P}{\partial T}\right)_E dE \quad (2)$$

Since the electrocaloric and magnetocaloric effects of currently known materials are, in general, too modest to be used directly in a real device, a heat-regeneration process must be applied in order to increase the temperature span of the device. This principle is well known from magnetic refrigeration. Fig. 1 shows the four basic operational steps of a magnetocaloric regenerator (active magnetic regenerator) and an electrocaloric regenerator, which are, in principle, analogous. The refrigeration process of both regenerators consists of the following four steps: magnetization/polarization of the magnetocaloric/electrocaloric material; applying a fluid flow (removing the heat from the material) while the material stays magnetized/polarized; demagnetization/depolarization of magnetocaloric/electrocaloric material; and applying a fluid flow when the material stays demagnetized/depolarized (material absorbs the heat).

### 1.1. *Brief overview of the electrocaloric effect and materials*

The phenomenon of the electrocaloric effect is not new in science and has been known almost as long as the magnetocaloric effect. However, the electrocaloric effect was, until

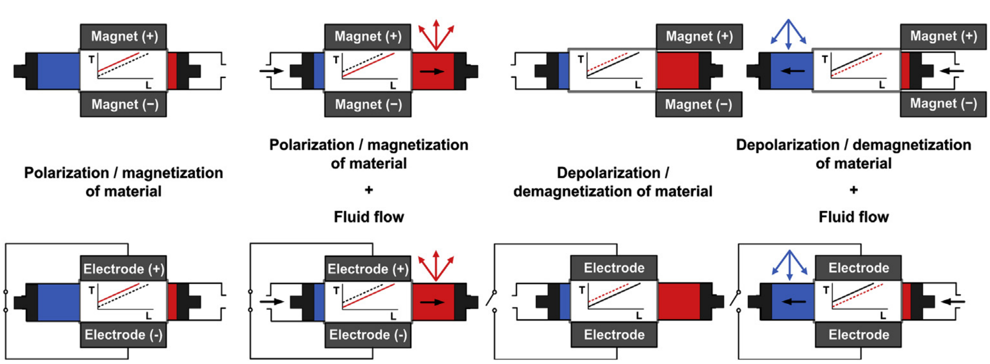


**Fig. 1 – Schematic presentation of the analogy between the cooling cycles that utilize magnetocaloric effect, i.e., a magnetocaloric regenerator (upper), and the electrocaloric effect, i.e., an electrocaloric regenerator (lower).**