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The Environmental Impact and Energy Efficiency of Magnetocaloric Refrigeration Systems:

An Assessment of Sustainable Refrigeration

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ABSTRACT

This research aims to provide a comprehensive assessment of the environmental impact and energy efficiency of magnetocaloric refrigeration systems compared to conventional vapor compression refrigeration. Through life cycle assessment (LCA) and thermodynamic modeling, this article will quantitatively analyze the potential reductions in greenhouse gas emissions and energy consumption achievable with magnetocaloric cooling technologies. The results will contribute to the ongoing efforts to develop more sustainable refrigeration solutions. Since magnetocaloric refrigeration is still in the development phase this study aims to fill the void of knowledge for this technology and its applications.

KEYWORDS

Magnetocaloric, Refrigeration, Sustainability, Refrigeration, Vapor Cycle

TOWARD SUSTAINABLE REFRIGERATION, ASSESSMENT OF ENVIRONMENTAL IMPACT AND ENERGY EFFICIENCY IN MAGNETOCALORIC REFRIGERATION SYSTEMS

Today, much of the world is utilizing a refrigerant-based system to heat and cool buildings and/or refrigerate products. The refrigerant-based system relies on changes of state (from liquid to gas and vice versa) to effectively move heat from one place to another. “Refrigeration is the process of removing heat from matter which may be a solid, a liquid, or a gas. It cools the matter by lowering its temperature through a sensible heat transfer which is a phase change process” (Dinçer, 2017). Figure 1 shows how the system is affected when varying pressure is applied.

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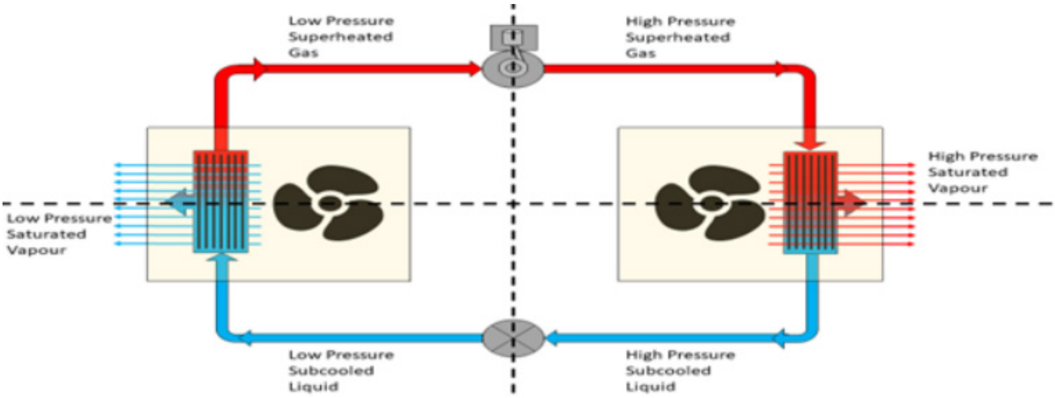
Figure 1. The refrigeration cycle



Note. From Torr Engineering (2020).

The term “refrigerant” is a very vague term used to describe a great variety of elements; this includes ammonia, carbon dioxide, and combinations of elements, such as R-410A, which has a near-azeotropic 50/50 weight % mixture of pentafluoroethane (HFC-125) and difluoromethane (HFC-32) (Yancey et al., 2022).

The greatest challenge with refrigerant-based systems is that during a product’s life cycle, the refrigerant can make its way to the earth’s atmosphere. Refrigerants used throughout the 21st century were found to have high global warming potential (GWP) and ozone depletion potential (Yadav et al., 2022). There are three distinct negative effects of refrigerant-based systems that need to be addressed by the technological community: the high use of energy, the use of toxic refrigerants, such as ozone-depleting and flammable greenhouse gases (GHGs), and a reliance on moving parts that require oil and/or maintenance.

> *In addition to consuming large amounts of energy, cooling services have historically used refrigerants with global warming potentials (GWP) that are many orders of magnitude greater than carbon dioxide. Despite the significant contributions to greenhouse gas (GHG) emissions, cooling services often do not receive much attention from the environmental community, possibly due to the distribution of cooling services across the building, transportation, and food sectors. (Dong et al., 2021)*

The key to environmentally sustainable refrigeration is to eliminate the process that requires refrigerant. One method to accomplish this is through magnetocaloric refrigeration. Like any innovative technology, hurdles still exist, but the magnetocaloric process can be the gateway to sustainable energy and a pollution-free future.

Magnetocaloric Refrigeration

The magnetocaloric refrigeration process, depicted in Figure 2, is based on the magnetocaloric effect (MCE). The MCE, or adiabatic temperature change, which is detected as magnetic materials are heated and cooled by a varying magnetic field, was originally discovered in iron by Emil Warburg in 1881 (Pecharsky & Gschneidner, 1999). Over the years, different organizations have worked to mainstream the technology.