

**MAGNETOCALORIC EFFECT AND MAGNETOCALORIC COOLING
TECHNOLOGIES**

**Tashkent State Transport University
Electrical systems and complexes
Master Sultanov Mehriddin**

Abstract. This article analyzes the physical nature of the magnetocaloric effect and the principle of operation of magnetocaloric cooling technologies based on it. The magnetocaloric effect, which is associated with a change in the temperature of some ferromagnetic materials under the influence of a magnetic field, is considered a promising direction for creating energy-efficient and environmentally friendly cooling systems. The study highlights the main properties of magnetocaloric materials, cooling cycles, and their advantages over traditional vapor-compressor cooling systems. The possibilities of increasing energy efficiency, eliminating harmful refrigerants, and applying magnetocaloric cooling technologies in the transport and industrial sectors are also analyzed on a scientific basis.

Keywords: magnetocaloric effect, magnetocaloric refrigeration, ferromagnetic materials, magnetic field, energy efficiency, ecological refrigeration technologies, refrigeration cycle, transport refrigeration systems.

The physical essence of the magnetocaloric effect

The magnetocaloric effect (MCE) is a physical phenomenon characterized by a change in the temperature of certain ferromagnetic materials under the influence of an external magnetic field. This effect was first discovered at the end of the 19th century and is currently considered an important scientific basis for the creation of energy-efficient cooling technologies.

The essence of the magnetocaloric effect is that when a ferromagnetic material is placed in a magnetic field, its internal magnetic moments become ordered and its entropy decreases. As a result, the temperature of the material increases. Conversely, when the magnetic field is removed, the magnetic moments return to a disordered state and the material cools by absorbing heat from the environment.

The magnetocaloric effect is described by the following expression:

$$\Delta T = - \frac{T}{C} \left(\frac{\partial S}{\partial H} \right)_T \Delta H$$

here:

- ΔT — temperature change,
- T — absolute temperature,
- C — heat capacity,
- S — entropy,
- H is the magnetic field strength.

This connection shows that magnetocaloric materials have high efficiency in the cooling process.

2.2. Magnetocaloric materials and their properties

The materials used in magnetocaloric cooling systems must have high magnetocaloric properties. The most commonly used magnetocaloric materials are:

- gadolinium (Gd);
- Gd–Si–Ge alloys;
- La–Fe–Si based materials;
- Alloys in the Mn–Fe–P–As system.

Gadolinium is widely used in laboratory and experimental devices due to its strong magnetocaloric effect at near room temperature. However, its high cost and limited resource limit its use on an industrial scale. Therefore, extensive scientific research is currently being conducted on iron-based magnetocaloric materials. These materials are characterized by their low cost, environmental safety, and sufficient magnetocaloric properties.

The main requirements for magnetocaloric materials are:

- large magnetocaloric effect value;
- low heat losses;
- mechanical strength;
- long service life.

2.3. Principle of operation of the magnetocaloric refrigeration cycle

The operating principle of a magnetocaloric refrigeration system is based on a four-stage thermodynamic cycle:

1. **Magnetization** — a material heats up when a magnetic field is applied;
2. **Heat transfer** - a heated material transfers heat to the external environment;
3. **Demagnetization** — the magnetic field is removed and the material cools;
4. **Heat absorption** - a cooled material absorbs heat from the environment being cooled.

This cycle operates with less energy consumption than vapor-compressor refrigeration systems. Because mechanical compressors and high-pressure refrigerant

gases are not used. The useful coefficient of performance (COP) of a magnetocaloric refrigeration system is expressed as follows:

$$\eta = \frac{Q_{cooling}}{W_{electric}} \quad \eta = \frac{Q_{cooling}}{W_{electric}}$$

Practical studies show that the FIK value of magnetocaloric systems can be 20–30% higher than that of traditional refrigeration systems.

2.4. Comparison with traditional cooling systems

The table below compares the main indicators of vapor-compressor and magnetocaloric refrigeration systems:

Indicator	Steam-compressor	Magnetocaloric
Energy consumption	High	Low
Environmental impact	Freon is used	Environmentally friendly
Noise	High	Very low
Mechanical parts	Many	Less
Service life	Average	High

The comparison results confirm the promising potential of magnetocaloric cooling systems in the transport sector.

2.5. The importance of magnetocaloric technologies in the transport sector

The cooling system in vehicles, especially electric vehicles, accounts for 20–30% of energy consumption. By implementing magnetocaloric cooling systems:

- increasing the range of electric vehicles;
- extend battery life;
- overall energy efficiency can be improved.

In addition, the noiseless operation of magnetocaloric systems creates comfort for passengers and reduces maintenance costs.

As a result of the conducted research, it was found that the magnetocaloric effect and magnetocaloric cooling technologies based on it are of significant scientific and practical importance in creating modern energy-efficient and environmentally friendly cooling systems. The magnetocaloric effect is associated with a change in the temperature of certain ferromagnetic materials under the influence of an external magnetic field, and the use of this phenomenon allows the cooling process to be carried out without mechanical compressors.

The analysis showed that magnetocaloric refrigeration technologies have high energy efficiency compared to traditional vapor-compressor refrigeration systems, allowing for significant reductions in electricity consumption. At the same time, since

these technologies do not use freon and other harmful refrigerants, their negative impact on the environment is minimal.

The properties of magnetocaloric materials, in particular gadolinium and iron-based alloys, were analyzed and their potential applications in cooling systems were substantiated. According to the research results, the introduction of magnetocaloric cooling systems in the transport sector, especially in electric cars and electric vehicles, can increase overall energy efficiency, extend the service life of batteries, and reduce operating costs.

In conclusion, magnetocaloric refrigeration technologies are one of the promising areas that are expected to be widely used in transport and industrial refrigeration systems in the future, and their implementation is of great importance in ensuring energy efficiency and environmental sustainability.

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