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A BASIC MAGNETIC REFRIGERATOR: USING THE MAGNETOCALORIC EFFECT

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ABSTRACT

With the cooling industry contributing to a consistent increase in global warming, the development of energy-efficient and environmentally friendly technologies has become crucial in reducing greenhouse gas emissions and mitigating climate change. Magnetic refrigeration presents a promising alternative, using the magnetocaloric effect to achieve cooling without harmful chemicals. This paper focuses on using gadolinium as the primary magnetocaloric substance while understanding the magnetocaloric effect at room temperature and developing a design for a commercial magnetic refrigerator.

KEYWORDS: Magnetic Refrigeration, MCE, Gadolinium, CFCs, Entropy. Magnetocaloric Effect

INTRODUCTION

The Montreal Protocol was established in 1987 to stop the production of refrigerators with chlorofluorocarbons (CFCs), which was believed to cause the depletion of the ozone layer (Gerretsen, 2020). This move was instrumental in reducing the impact that refrigerators have on the environment. However, it did not make them completely environment-friendly. This industry still releases more carbon dioxide into the air than the aviation and shipping industries combined (Birmingham Energy Institute, n.d.). The substitutes of CFCs - hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) - have more than a thousand-time global warming potential (GWP) than carbon dioxides, and they can create a much stronger greenhouse effect (Myhre et al., 2013).

Thus, the need for a more environment-friendly refrigeration system has never been stronger. With the magnetocaloric effect being heavily researched and gaining traction, magnetic refrigerators could well become the future.

Thesis

Understanding the magnetocaloric effect and investigating an ideal magnetocaloric substance to design a basic prototype of a magnetic refrigerator that could replace conventional refrigerators that release harmful gases.

LITERATURE REVIEW

The article by Gerretsen (2020) discusses the impacts of the cooling industry, which includes refrigerators and air conditioners, on the environment using data from different sources such as Birmingham Energy Institute, (n.d.) and Myhre et al. (2013). They highlight the adverse effects caused by the current cooling industry and help show the need for a new kind of refrigeration process.

The paper by de Oliveira & von Ranke (2010) investigates the magnetocaloric effect by understanding the change in magnetocaloric potential when multiple variables are changed (pressure, doping, etc.). It helps explain the reason behind the magnetocaloric effect. Similarly, the paper by Mezaal et al. (2017) investigates the effectiveness of the magnetic refrigeration system compared to traditional refrigeration systems. It discusses ideas on what magnetocaloric substances to use to maximize the refrigeration system's efficiency, which helps explain why gadolinium was chosen.

The paper by Pecharsky & Gschneidner (2007) investigates the different kinds of magnetocaloric effects produced while taking gadolinium as the magnetocaloric substance. It helps in providing primary data to analyze conditions required in the magnetic refrigerator and in understanding the feasibility of using Gadolinium as the magnetocaloric substance in magnetic refrigerators. Moreover, the paper by Zul et al. (2024) was recently published and focuses on discovering more effective and cost-efficient magnetocaloric substances. It helps in showing that recent developments are being made and gadolinium is not the only substance that can work.

The Magnetocaloric Effect

The Magnetocaloric Effect (MCE) occurs as a result of variations in the strength of a magnetic field. In the absence of an external magnetic field, the magnetic moments within a magnetic material (which could be ferromagnetic or paramagnetic) are typically disordered. Upon exposure to a magnetic field, these moments align in the direction of the magnetic field, leading to an ordered configuration (de Oliveira & von Ranke, 2010). Since the magnetic moments are less disordered, the material's entropy would decrease. The reduction in entropy corresponds to a decrease in the material's internal energy, and the energy that was previously associated with the disordered magnetic moments is released as heat, causing the material to heat up. Conversely, when the material is moved out of a magnetic field, its magnetic moments become randomly disordered, which increases its total entropy. The material's entropy increases, which can be achieved by taking in energy from the surroundings, so absorption of energy results in cooling of the substance. For ferromagnets, the magnetocaloric effect is most pronounced near the material's Curie temperature, where the material transitions between ferromagnetic and paramagnetic phases. In contrast, for paramagnets, this effect is most significant at temperatures approaching absolute zero.

Magnetocaloric Substance in Magnetic Refrigerators

The most commonly used magnetocaloric substance in experiments is gadolinium, and some researchers believe that it should be used as a refrigerant in magnetic refrigerators. This is because its Curie temperature is near room temperature (293K), and it also does not have any magnetic or thermal hysteresis taking part in second-phase transitions (Mezaal et al., 2017).

Figure 1 is a graph that shows the change in the temperature of gadolinium based on the change in magnetic field strength (ΔB, measured in Tesla) and the initial temperature of gadolinium.

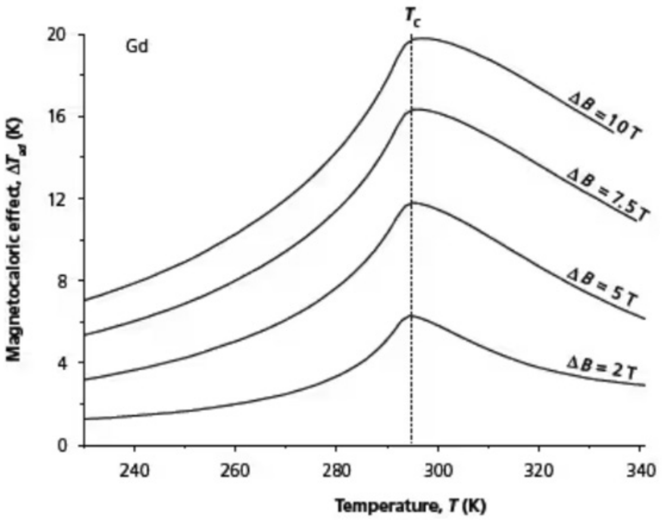

Figure 1: Pecharsky & Gschneidner (2007)

Using Figure 1, the optimum magnetic field strength to get a temperature of 274 K–278 K would be 10 Tesla at 296 K for Gadolinium. A common misconception is that gadolinium is a rare metal and is very difficult to obtain, which makes them question the feasibility of incorporating it into necessities like refrigerators. However, it is abundant in the Earth's crust and can be extracted from minerals such as monazite. Additionally, research is underway to find an even better alternative that is cheaper and has better chemical stability than gadolinium. Researchers have found perovskite manganites as potential replacements, but they may still take time to enter the market (Zul et al., 2024).

Magnetic Refrigerator Model

The Magnetic Refrigerator works based on MCE: a magnetic field is generated, and a magnetic substance's temperature changes based on that. The cycle starts with the substance's temperature increasing due to the presence of the magnetic field. Similar to a commercial vapor-compression refrigeration system, a heat transfer fluid (HTF) will expel the heat generated. After that, when the magnetic field is removed, the magnetic substance absorbs heat from the refrigerator, reducing the temperature. This cycle regulates the refrigerator's temperature (Mezaal et al., 2017).

The basic framework of a magnetic refrigerator could use the above process to its advantage. A box containing gadolinium would be positioned at the bottom with two strong electromagnets on the sides to generate the required magnetic field. These boxes should also have fans in the corners working similarly to exhaust fans to expel any heat generated within the box. There would be tiny pipes containing an HTF, such as water, which can transfer heat easily throughout the box and between the spheres. This pipe should extend to the top of the refrigerator and be connected to a heat exchanger to make transferring heat much quicker. There should be a valve at the box's entrance in the pipe. The gadolinium becomes hotter when the magnetic field is created, and the fans expel the heat. The valve would also be shut, preventing HTF from entering the box. When no current passes through the electromagnet, the magnetic field strength becomes null, and the substance becomes much cooler, which is then transferred to the HTF. The HTF circulates it throughout the fridge. Fans could be placed in the fridge to control and enhance the airflow.

CONCLUSION

This theoretical model is very basic, and ideas could be built upon it to make the circulation and transfer of heat more effective. However, this model eliminates the risk of releasing harmful pollutants into the atmosphere. The development and commercialization of this technology could play a massive role in reducing the cooling industry's carbon footprint and aligning with global climate goals.

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