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ANALYSIS AND EFFICIENCY OF A GADOLINIUM MAGNETOCALORIC MATERIAL PLATE

ANALIZA IN UČINKOVITOST GADOLINIJSKE MAGNETOKALORIČNE PLOŠČE

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Abstract

In this article, the influence of a controlled magnetic field on gadolinium plates was modelled and simulated to be used in magnetic refrigeration installations. This is a state-of-the-art technology that does not use refrigerants and does not work based on vapour compression, which is based on the operation of the magnetocaloric properties of the material used; in the case below, this material, in the form of a flat plate, has certain magnetocaloric properties and under the influence of magnetic induction can be used successfully in such innovative installations. The advantages of using gadolinium in the form of a flat plate in a magnetic regenerator and thermal energy dissipation on its surface under the controlled magnetic field's influence were studied.

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Povzetek

V tem članku je bil izdelan model in simuliran vpliv nadzorovanega magnetnega polja na gadolinijeve plošče za uporabo v magnetnih hladilnih napravah. To je najsodobnejša tehnologija, ki ne uporablja hladilnih sredstev in ne deluje na osnovi kompresije hlapov. Tehnologija temelji na delovanju magnetokaloričnih lastnosti uporabljenega materiala; v spodnjem primeru ima ta material v obliki ravne plošče določene magnetokalorične lastnosti in se pod vplivom magnetne indukcije lahko uspešno uporablja v inovativnih instalacijah. Proučene so bile prednosti uporabe gadolinija v obliki ravne plošče v magnetnem regeneratorju in odvajanja toplotne energije na njegovi površini pod vplivom nadzorovanega magnetnega polja.

1 INTRODUCTION

Magnetic refrigeration is a new technology that uses the magneto-caloric effect developed in the solid-state to produce a refrigeration effect, [1]. Modern society is highly dependent on reliable refrigeration technology. Without it, the food supply would be seasonal and limited to local, non-perishable products. and comfortable living conditions would not be possible. Furthermore, many medical advances, for example, MRI, organ transplantation, tissue and organ cryogenics and cryosurgery, would be impossible. Surprisingly, all these and other developments in obtaining and maintaining temperatures below ambient temperature are supported by technology that remains essentially unchanged since it was invented more than a century ago. Refrigeration close to room temperature is based entirely on a vapour-compression refrigeration cycle. Over the years, all parts of a commercial refrigerator (i.e., the compressor, the heat exchangers, the refrigerant and the packaging) have been improved due to the extensive research and development efforts carried out by academia and industry. However, both recent and anticipated improvements in technology are on the rise, as refrigeration is already close to the fundamental limit of energy efficiency.

Furthermore, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), and other chemicals used as refrigerants are hazardous to the environment and cause ozone depletion and global warming; therefore, vapour compression refrigeration contributes significantly to the impact of the environment in which we live. Refrigeration is defined as the use of a mechanism that changes its temperature in response to certain thermodynamic transformations to cool an object or an environment. These variations must be made quickly and repeatedly, reversibly, and with minimal energy losses. Both the heating and cooling of soft ferromagnetic materials in response to the increase and decrease of the magnetic fields have been known since the second half of the 19th century, when Warburg (1881) reported a small but measurable temperature change in pure iron in response to the changes in the magnetic field. Today, this phenomenon is known as the Magnetocaloric Effect (MCE) and the materials that show large, reversible changes in temporary temperature in response to changing magnetic fields are usually called magnetocaloric materials.

Magnetic refrigeration that uses solid materials such as gadolinium (Gd) as a refrigerant illustrates the MCE, where there is an increase or decrease in temperature when magnetized and/or demagnetized, respectively. Recently, materials have been developed in which there are sufficient changes in temperature and entropy, which makes them useful for applications at high temperatures. Effective and current solutions for reducing energy consumption using magnetic materials include the use of permanent magnets as sources of magnetic fields in electrical systems and materials with MCE in magnetic refrigeration systems at room temperature. These systems' energy efficiency is closely linked to the proper choice of the magnetic materials involved according to the targeted performance requirements and the technological implementation solutions at acceptable cost prices.

Magnetic materials are a class of materials that are characterized by magnetization states with useful functions. The phrase "state of magnetization" means that the state of matter characterized by magnetic moment of the unit of volume other than zero.

It is atomic in nature, being generated by the movement of electrons in orbit and around its own axis; these movements give rise to magnetic moments. The magnetization state of a magnetic material can be temporary, when it depends on the existence of an external magnetic field and cancels with it, or permanent, when it is independent of the existence of an external magnetic field.

2 LITERATURE REVIEW

There are many scientific articles, patents, and books in which researchers have highlighted the benefits of using magnetocaloric materials for refrigeration processes, and the potential of such materials has been demonstrated as an effective material for saving energy. Gao et al. explained in detail the transformation of magnetocaloric energy from materials, where the relevant disadvantages were also explained, *[2].*

In both Europe and the US, a huge amount of energy could be saved from conventional refrigeration and air conditioning by approaching magnetic refrigeration.

The main reason for the increased interest in magnetic refrigeration is its ecological operation, extreme energy efficiency and the complete removal of refrigerants harmful to the ozone layer and the environment, *[3].*

The research leads to the development of the refrigeration equipment that can operate at room temperature. There have been various successful attempts at the prototype or experimental levels, such as products developed by General Electric and Haier.

The properties that can be used in refrigeration installations are due to the extraordinary response of these materials to external magnetic fields; the exposure of such properties takes place close to Curie temperature (i.e., the temperature at which the self-possessed basic magnetic properties decrease and the material temperature depends by applying the magnetic field), *[4].*

The magnetocaloric effect has been used since 1920 to examine the magnetic structure and properties of iron and other related elements of various materials, *[5].*

Research tends to develop important developments and highlight the exponential progress that led to Toady's knowledge and understanding of the magnetocaloric effect. Faraday discovered that the variation in magnetic flux over time results in the induction of electric currents, *[6].* Joule explained the idea related to electric currents and associated thermal energy, stating that the thermal energy released due to the induced magnetic induction is equivalent to the thermal energy produced, and the rapid magnetization and demagnetization can lead to the heating of the magnetocaloric material due to applied thermal energy, *[7].*

3 MODELLING BOUNDARIES

The modelling and simulation of processes for gadolinium (Gd) plates were performed in COMSOL Multiphysics software. The 3D model was drawn in the "mesh geometry" tab of the Comsol software, and the symmetry is shown in Fig.1.

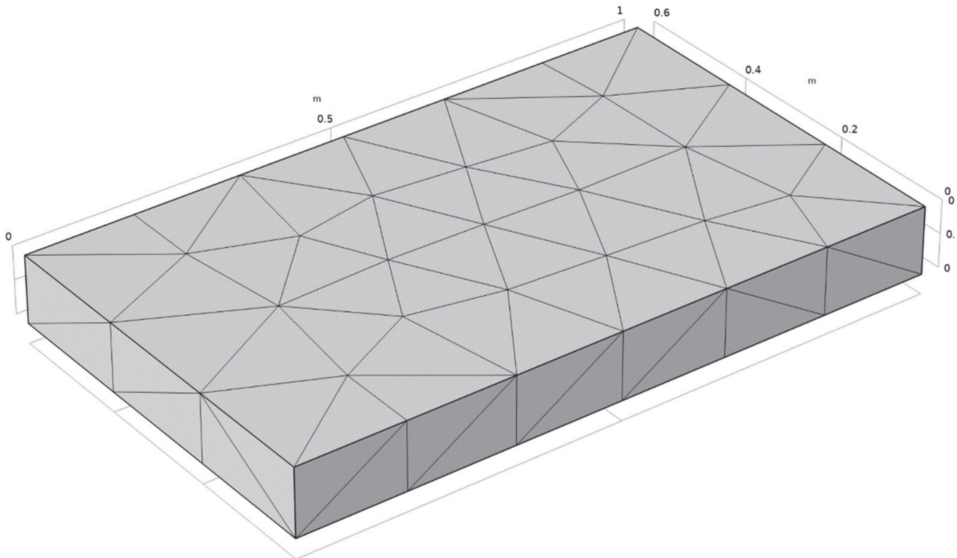

Figure 1: *Comsol 3D mesh plan for Gd plate*

The length of the plate is 100 cm, while the height is 10 cm, and the width is 60 cm. The table below shows the full dimensions of the model.

Table 1: *Gd plate dimensions*

Name	Expression	Value
L(length)	100[cm]	1 m
B(height)	10[cm]	0.1 m
W(width)	60[cm]	0.6 m

The physics selected for the simulation is the main determinant of the solution and the boundary conditions. The models that were used in the simulation are magnetic fields, heat transfer in solid materials, and laminar flow for fluid solvers, *[8].*

All these coupled found the numerical solution of the problem of the magnetocaloric effect of the Gd plate, which can be used successfully in magnetic regenerators.

The magnetocaloric effect in the COMSOL Multiphysics, model was introduced using an interpolation function of the thermophysical data.

$$M, C_p, \Delta T_{ad} = f(T, \mu_0, H(t))$$

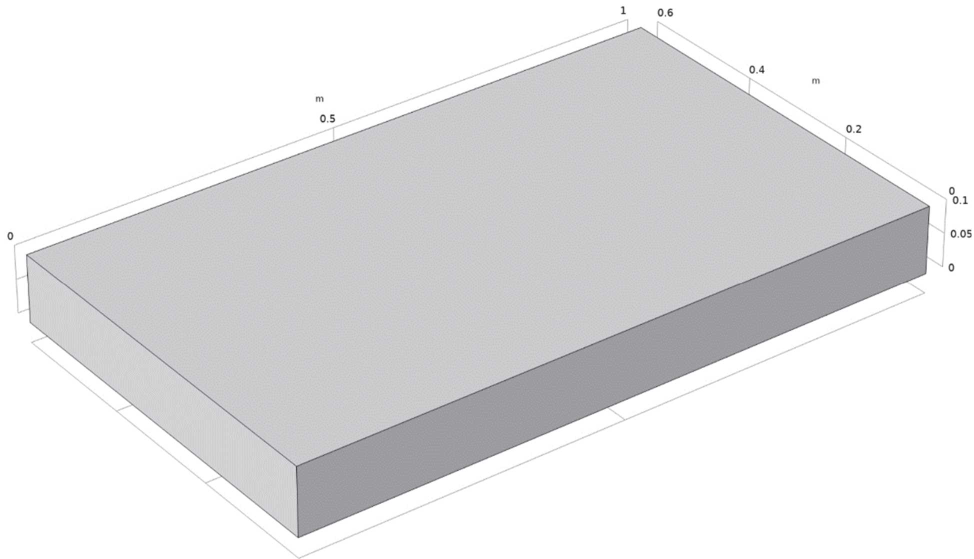

***Figure 2**: Gd board model. 3D*

4 RESULTS

Figure 3 shows the temperature profile on the surface of the Gd plate; the temperature begins to dissipate slowly due to the effects of thermal convection.

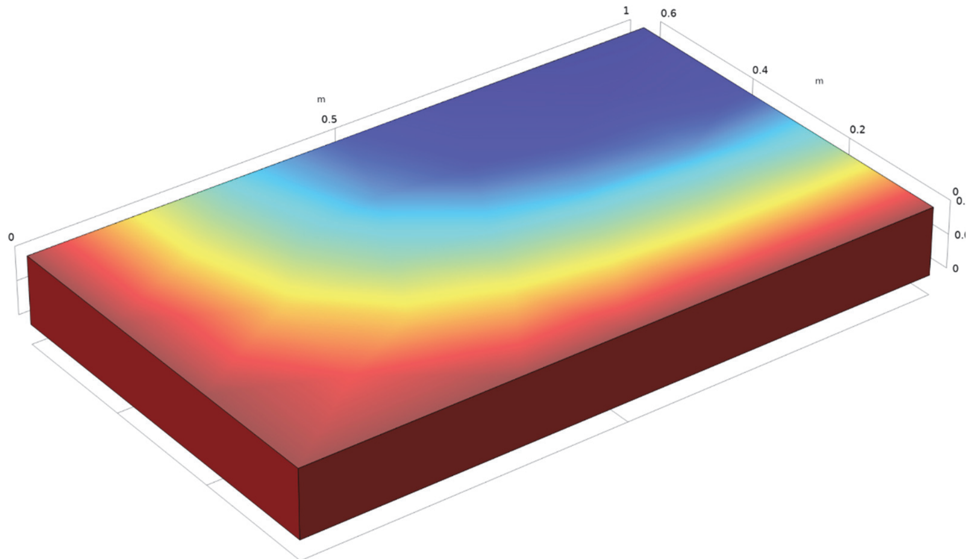

Figure 3: *Gd board temperature profile. 3D modelled in COMSOL*

The decrease in temperature due to the decrease in the magnetocaloric effect is similar to the reports made in research journals, *[9].* Successful simulations were performed using the COMSOL model, and the transient model can be adopted for another approach. The chosen material (Gd) is widely used in research in the field of magnetocaloric materials, *[10-13].*

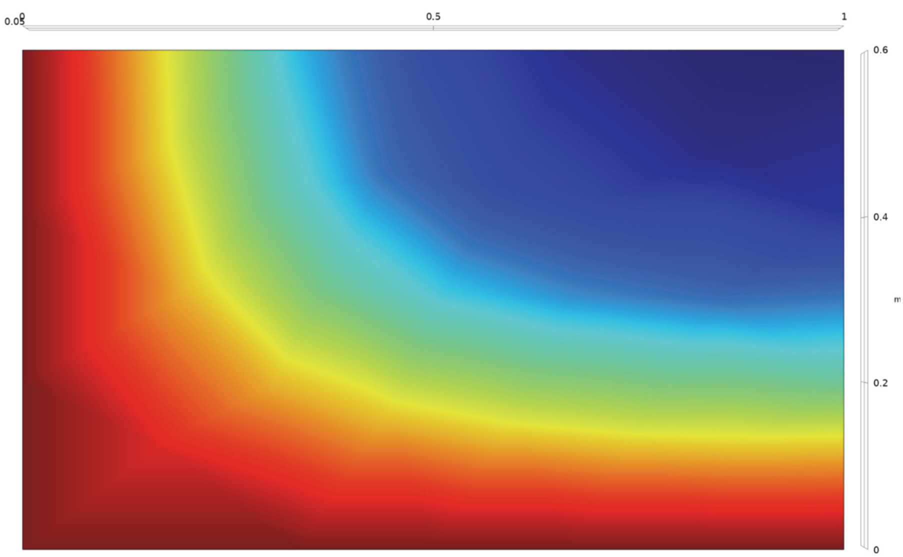

Figure 4: *The temperature profile of the Gd plate. on the xy*

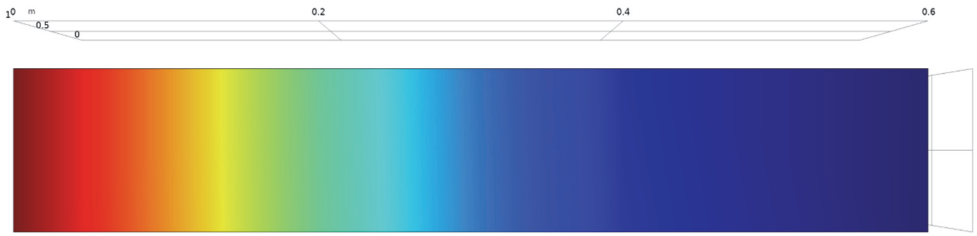

Figure 5: *The temperature profile of the Gd plate. on the yz*

Table 2: *The properties mostly used for gadolinium*

Tangent coefficient of thermal expansion	1/K	Thermal expansion
Isotropic tangent coefficient of thermal expansion	1/K	Thermal expansion
Thermal conductivity	W/(m·K)	Basic
Heat capacity at constant pressure	J/(kg·K)	Basic
Density	kg/m^3	Basic
Resistivity	Ω·m	Basic
Coefficient of thermal expansion	1/K	Basic
Electrical conductivity	S/m	Basic
Local property HC	J/(mol·K)	Local properties
Local property VP	Pa	Local properties
Local property TD	m^2/s	Local properties

The model selected for simulation and modelling is a determining factor of the solution and the limit.

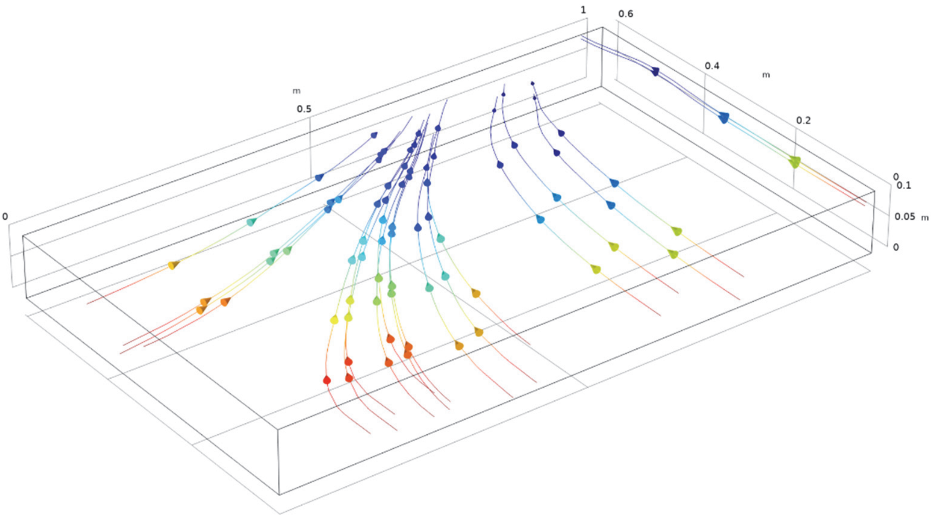

Figure 6: *Gd plate temperature flow profile in 3D*

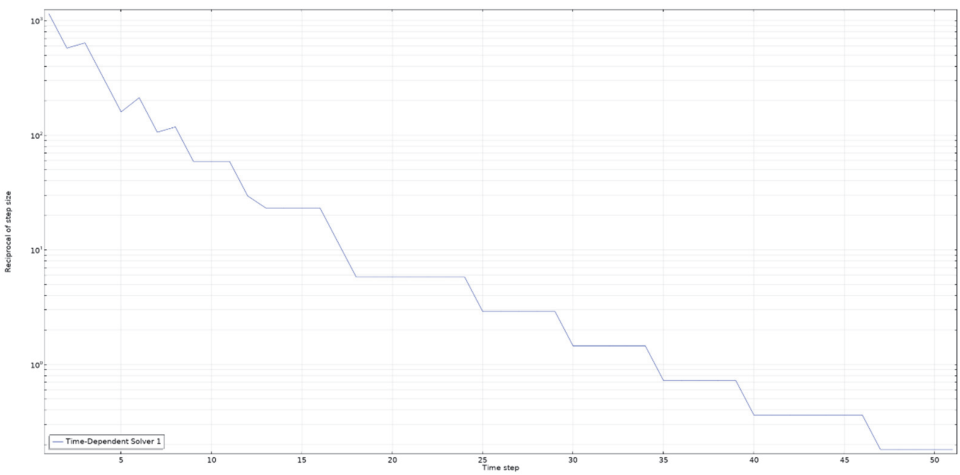

Figure 7: *The evolution of the temperature flow and the dispersion in time on the surface of the Gd plate*

Figure 6 presents the evolution of the temperature variation on the whole surface of the Gd plate, inside the magnetic regenerator (AMR) and for about 50 minutes.

5 CONCLUSION

In this article, the modelling and simulation of the Gadolinium board were performed in COMSOL Multiphysics software. The study of this material focused on the dissipation of heat flow on the integral surface of the material, the properties of the material and the orientation of the dipole moments. The research provides important perspectives on this field and is based primarily on magnetocaloric testing in magnetization conditions with directions for further development in the development of prototypes and magnetic installations. This study requires the understanding and knowledge of the thermodynamic principles of operation of magnetocaloric refrigeration installations. The simulation began with the magnetization of the Gd board, using the limit condition of Ampere's law, which is governed by the modulus of the magnetic field.

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