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A test stand to study the possibility of using magnetocaloric materials for refrigerators

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ABSTRACT

A laboratory test stand for magnetocaloric effect investigations has been developed. The test stand is compact and easily reconfigurable. Gadolinium in the form of particles is used as a refrigerant. The material is magnetized/demagnetized due to the reciprocating motion of a magnetic bed. A Halbach array of permanent magnets is employed as a magnetic field source. It generates a magnetic field of about 1 T. In order to decrease the distance along which the magnetic bed has to move, a magnetic shield was used which limits the range of external magnetic field influence. The effectiveness of the shielding and the decrease in magnetic field intensity were shown in the form of magnetic field distribution maps. The paper presents first experimental results which are measured as the temperature difference between the two outermost reservoirs. The achieved results are promising – the temperature span between the heat exchangers amounts to about 2 °C.

Un banc d'essai pour étudier la possibilité d'utiliser des matériaux magnétocaloriques dans les réfrigérateurs

Mots clés : Effet magnétocalorique ; Froid magnétique ; Refroidissement magnétique ; Gadolinium

1. Introduction

Refrigeration based on the magnetocaloric effect is a modern way to decrease temperature. This method is environmentally friendly because, unlike traditional technology which consists in expansion and compression of gases, it does not employ chlorofluorocarbon gases which contribute to the greenhouse effect. Moreover, magnetic refrigerators are characterized by a higher efficiency compared with commonly used cooling appliances (Yu et al., 2003). This paper presents a laboratory test stand for magnetocaloric effect investigations in materials with transition temperatures close to room temperature. The test stand has a modular structure so that any configuration can be easily applied during tests. In this way the system may be optimized to achieve larger temperature differences between reservoirs while consuming less electrical energy. A cylindrical magnetic bed was filled with a magnetocaloric material, gadolinium, in the form of particles

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Nomenclature

AMR	active magnetic regenerator
B	magnetic induction (magnetic flux density)
COP	coefficient of performance
COPe	electrical coefficient of performance
DC	direct current
HEX	heat exchanger
PC	personal computer
Q	flow rate of heat transfer medium
SEM	scanning electron microscope
Tc	temperature measurement point (thermocouple)
Greek symbols	
ΔT	temperature difference

with dimensions ranging from 2 to 5 mm. Halbach array of cylindrical shape was used as magnetic field source. This special arrangement of permanent magnets generates a maximum magnetic field of 1 T inside its inner gap.

2. Experimental apparatus design

2.1. Construction of the test stand

A scheme of the test stand is presented in Fig. 1. The stand is composed of the following elements: a magnetic bed filled with the magnetocaloric material – gadolinium, a magnetic field source – Halbach array with a magnetic field screen, a peristaltic pump, hot and cold reservoirs (Hot and Cold HEX) and a measurement and control system. A design of the Cold HEX is similar to a typical piston – it changes its volume during the flow of a heat transfer fluid.

Fig. 2 shows the actual appearance of the test stand. A tube (1) is the basic structural element of the system. Inside the tube a magnetic field source is placed along with a magnetic bed and its tracks. The magnetic bed moves in a reciprocating motion, ensuring that the magnetocaloric material is cyclically magnetized and demagnetized and therefore changes its temperature. Hot (2) and cold (3) reservoirs are located on both ends of the tube. The heat emitted by the magnetocaloric material when the magnetic bed is inside the magnetic field is transferred to the hot reservoir. The temperature of the cold reservoir is lowered thanks to the heat absorption by the material filling the magnetic bed which occurs when the bed leaves the magnetic field. In order to log and control the results a computer (4) with an acquisition system was used. The computer is connected with a microcontroller (5) which manages the operation of the system. A testing program contains data with times and velocities of the fluid flow and magnetic bed movement. The program is prepared on the PC and is sent to the microcontroller where it is executed. In the designed test stand the magnetocaloric material serves both as the refrigerant and as the regenerator. Such system configuration is known as Active Magnetic Regenerator – AMR (Barclay and Steyert, 1982).

2.2. Magnetocaloric material and magnetic bed

Gadolinium was used as a magnetocaloric material because of its transition temperature close to room temperature. The material was purchased from the Sigma Aldrich company in the form of ingots. According to the producer the material has a purity of 99.99%. Fig. 3 shows images of gadolinium obtained with the aid of a Scanning Electron Microscope (SEM). One can notice numerous pores occurring in the material that may have some influence on the material's thermal conductivity.

To determine the magnitude of the magnetocaloric effect in the material, changes of its thermal capacity as a function of temperature and magnetic field were examined. On the basis of these data the temperature changes in the material were calculated (Fig. 4), based on the method described in Tishin and Spichkin (2003). The maximum ΔT of 2.5 °C was obtained for a temperature of 287 K.

The purchased gadolinium ingots required processing. A decision was made to reduce the material dimensions by cutting because smaller particles would offer faster heat exchange. The material was broken up with the use of a guillotine and then it was sieved to group it into fractions of gadolinium particles. 30 g of the magnetocaloric material, ranging from 2 to 5 mm in size, were used to fill the magnetic bed (Fig. 5).

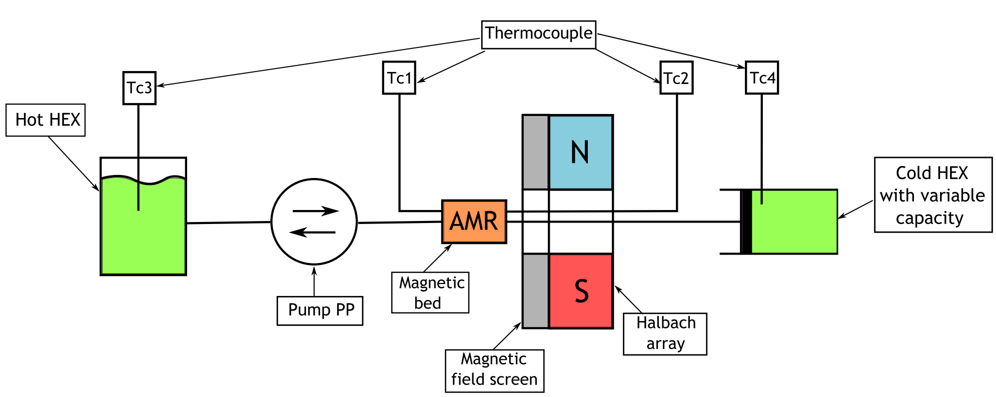

Fig. 1 – Scheme of the laboratory test stand.