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A LABORATORY TEST STAND FOR STUDIES OF MAGNETOCALORIC MATERIALS

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Abstract: *The paper presents a test stand to study the magnetocaloric effect. The stand utilises a magnetocaloric material, gadolinium, as a refrigerant. This material was chosen, because of good magnetocaloric properties and suitable work temperature close to the room temperature. The magnetic field of 1 T is generated by cylindrical Halbach array which is a special arrangement of permanent magnets that concentrate and homogenize the magnetic field in the inner gap of the flux source. As a heat transfer medium a special liquid was selected. In addition, the paper provides first results from an investigation. Results amounted to 1.6 ºC temperature difference between hot and cold heat exchanger.*

Key words: *smart materials, magnetic refrigeration, gadolinium.*

1. Introduction

Refrigerator is one of commonly used appliance in a kitchen. This device operates based on compression and expansion of the chlorofluorocarbon gases. The big disadvantage of the refrigerator is an environmental hazard associated with escape of the gases and their harmful influence on the Earth's ozone layer. The other drawback of these machines is small efficiency. However there are also another technologies that provide to temperature decreasing. One of them is the so-called magnetocaloric effect. This is thermodynamic phenomenon that works on magnetic field changes. When the magnetocaloric material enters the magnetic field its temperature rises, whereas after leaving the magnetic field temperature of the material decreases. The biggest temperature change is close to the Curie temperature which is specific for every material. In this temperature ferromagnetic substance becomes paramagnetic. Refrigerators that employ the magnetocaloric effect are environmentally friendly and have higher efficiency than commonly used fridges, hence interest in this filed is increasing.

Magnetocaloric effect was observed for the first time in 1881 [4]. The temperature change was noticed in the iron sample. Initially magnetocaloric effect was used to helium liquefaction. The first magnetic refrigerator prototype was built in 1974 by Brown [2]. This device was employing gadolinium as refrigerant and a

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superconducting magnet to generate the magnetic field of 7 T. Brown's prototype achieved temperature span between exchangers amounted to 47 ºC.

The paper reports on progress in developing the test stand to research into magnetocaloric materials.

2. Construction of the device

Figure 1 presents a scheme of the device. One can see that the test stand consists on several main parts: magnetocaloric bed filled with magnetocaloric material, magnetic flux source, heat transfer system, Hot Heat Exchanger (HHEX), Cold Heat Exchanger (CHEX), control system and cooling subsystem.

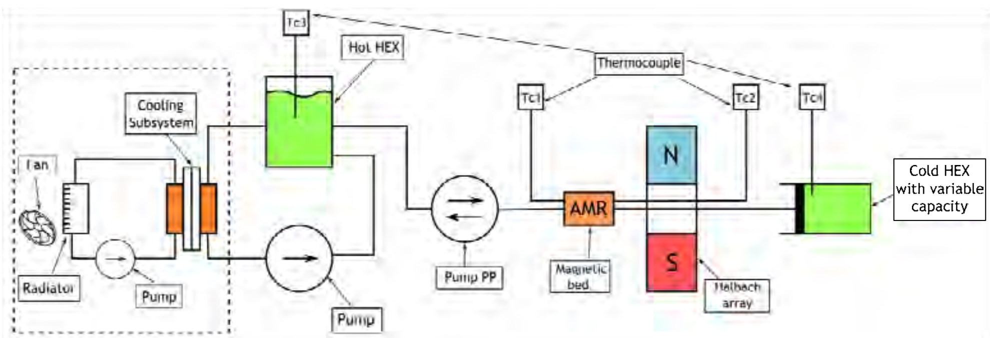

Fig. 1 *Scheme of the laboratory test stand*

2.1. Magnetic bed and magnetocaloric material

The magnetic bed (Figure 2) was made of plastic. A purpose of using plastic for bed housing was to provide thermodynamic

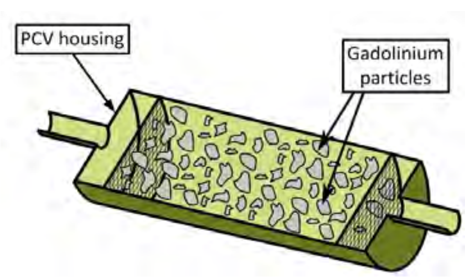

Fig. 2 *Construction of the magnetic bed*

conditions close to the adiabatic conditions. The housing is cylindrical with a diameter of 25.4 mm and is 25 mm in length. The magnetocaloric material is placed between two gauzes, hence during fluid flow process material remains in its place. On the each side of the magnetic bed is one inlet/outlet that enables for fluid flow. Magnetic bed reciprocates relative to the magnetic flux source, hence magnetocaloric material is alternately magnetized and demagnetized.

Fig. 3 *Gadolinium particles filling the magnetic bed*

The magnetocaloric material employed in the device is an element gadolinium. Gadolinium is a rare earth metal. This material stands out from elements, because of its relatively big temperature change associated with exposure on a magnetic field influence. Magnetic field in a value of 1 T causes about 2.5 ºC temperature change in the gadolinium [1] in its transition temperature which is close to the room temperature (~21 ºC). The magnetocaloric material that fills the magnetic bed is in the form of particles (Figure 3) ranging from 2 to 5 mm and has purity amounting to 99,99%. The material was purchased in the form of ingot. In order to speed up heat exchanging process dimensions of ingots were reduced by cutting.

2.2. Magnetic flux source

The Halbach array (Figure 4) was used as a magnetic field source. This array is in the shape of cylinder and in the centre has cylindrical gap. The gap diameter amounts to 25.4 mm, while the length equals 25 mm. The Halbach array was composed of several permanent magnets. Special arrangement of magnets causes homogenization and concentration of the magnetic field in the inner gap. The Halbach array generates the magnetic field of 1 T.

Fig. 4 *Photograph of the used Halbach array*

2.3. Heat transfer system

Heat transfer system is built out of two heat exchangers (cold and hot), pump, heat transfer medium and elastic pipes connecting heat exchangers with magnetic bed. Hot heat exchanger can exchange temperature with environment, whereas cold heat exchanger is insulated. In order to transfer heat between heat exchangers and the gadolinium a special liquid was chosen. This fluid is named “DP Ultra” and is produced by “Aqua Computer” company. “DP Ultra” liquid is usually used to decrease a computer temperature. The heat transfer medium is pumped by a peristaltic pump.

2.4. Auxiliary cooling system

The auxiliary cooling system is used to set and maintain temperature in the hot heat exchanger at desirable level. This system is based on Peltier effect and was built out of four Peltier’s modules. The hot side of the system was fitted with a fans to dissipate generated heat.

2.5. Control system

Registering and controlling of the results is accomplished by personal computer with acquisition system. The computer was connected with a microcontroller that was employed in order to manage the system’s operation. Control program with times, velocities and accelerations of the fluid flow and magnetic bed movement is created by the computer. In the next step this program is sent to the microcontroller and eventually microcontroller carries out control program at the laboratory test stand.

2.6. Work cycle

Magnetic refrigerators can be based on different work cycles. The most popular is an Active Magnetic Regenerator (AMR) work cycle [3]. In this cycle the magnetocaloric material acts not only as refrigerant, but also as regenerator. The presented laboratory test stand utilises this type of work cycle. The AMR cycle is shown in Figure 5. Colours of the magnetic bed and heat exchangers indicate direction of temperature changes. Green colour marks initial temperature, blue indicates temperature decreasing ($\Delta T<0$), while red marks temperature rising ($\Delta T>0$). The AMR work cycle is built out of four processes:

(0) Initial state,
(1) Adiabatic magnetisation process (magnetocaloric material is magnetized and its temperature rises),
(2) Isofield cooling process (medium absorbs heat from the magnetocaloric material and expels heat to the HHEX, HHEX is not insulated, hence expels heat to the environment),
(3) Adiabatic demagnetization process (magnetocaloric material is demagnetized and its temperature drops),
(4) Isofield heating process (medium expels heat to the magnetocaloric material and absorbs heat from CHEX),
(5) = (1) cycle is repeated from the first process (adiabatic magnetisation).

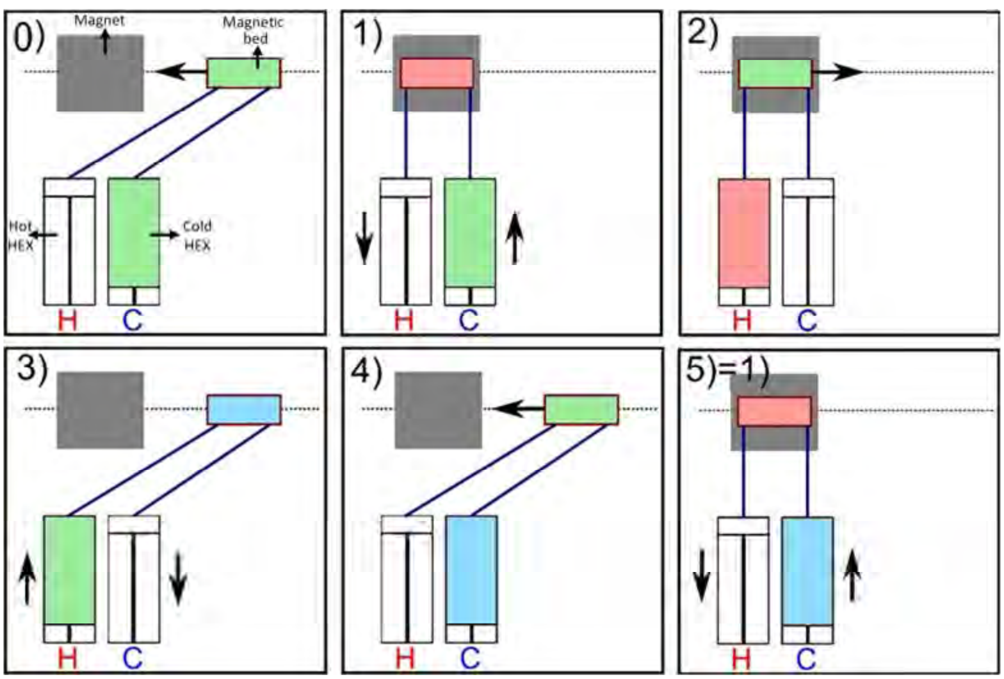

Fig. 5 *AMR work cycle*

Figure 6 presents chart which shows when the magnetocaloric material is undergone the influence of the magnetic field and when the heat transfer medium is pumped. The blue line marks time for liquid flow from the hot heat exchanger to the cold heat exchanger. One can see that this process is performed when gadolinium is outside the magnetic field. During the magnetic bed movement (black line) there is no fluid flow. When the magnetic bed is inside the Halbach array the heat transfer medium flows from the cold heat exchanger to the hot heat exchanger (red line).

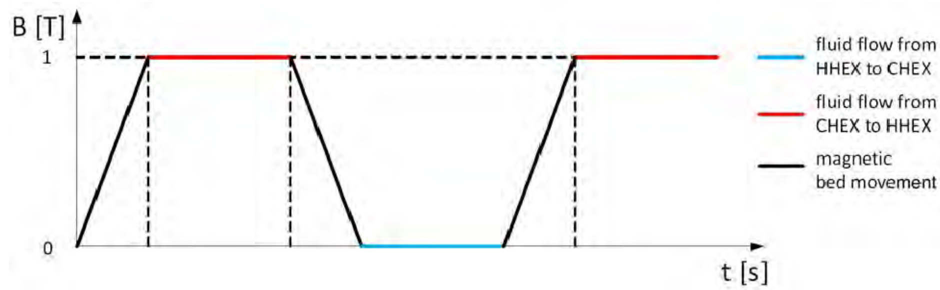

Fig. 6 *Chart of the laboratory test stand operation*

3. Experimental results

The preliminary tests were run without using auxiliary cooling system. Outputs from the experiment are presented in fig. 7. During experiment the temperature was measured in two points: hot heat exchanger (red line) and cold heat exchanger (blue line). The room temperature in which test was run amounted to about 25.3 ºC. Initial temperatures of the heat transfer medium in heat exchangers were close to the environmental temperature. The experiment lasted about 2000 s. After this time the temperature difference between heat exchangers increased to 1.6 ºC. One

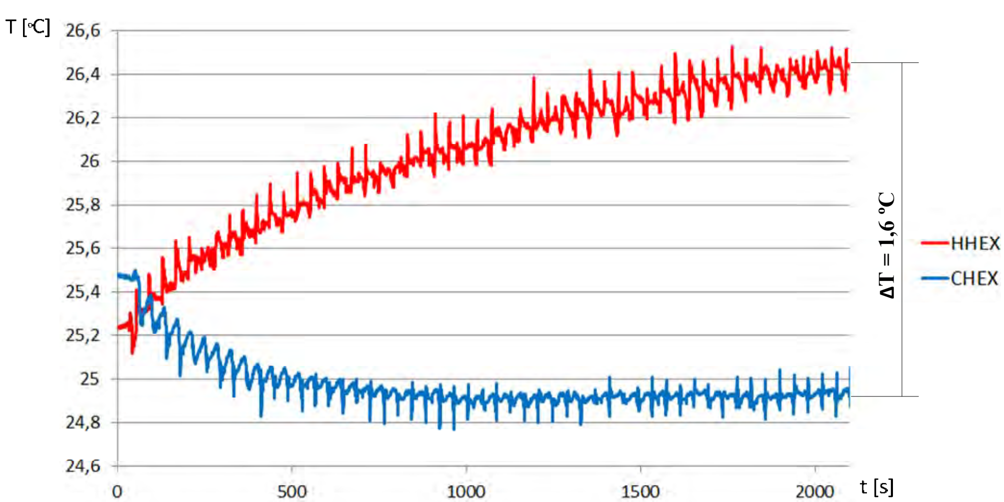

Fig. 7 *Temperature difference between heat exchangers*

can see that after 1000 s temperature of the cold heat exchanger decreased to the lowest value and then temperature was exchanger was increasing during whole measurement time. It can be caused not only by magnetocaloric material work, but also by peristaltic pump, because the pump was placed between the hot heat exchanger and the magnetic bed.

4. Conclusions and outlook

The laboratory test stand to magnetocaloric effect investigations was presented. The test stand employed gadolinium as refrigerant as well as regenerator. The magnetocaloric material purity is very high, amounts to 99,99 %. The material was utilised in form of particles ranging from 2 to 5 mm. The magnetic flux is generated by the special arrangement of permanent magnets, so-called Halbach array. Generated magnetic field in the inner space is in a value of 1 T. “DP Ultra” liquid that is produced by “Aqua Computer” company was used as a heat transfer medium.

The preliminary experiment was run in room temperature amounted to 25.3 ºC. This test took 2000 s. The experiment enabled to achieve temperature difference between heat exchangers equals 1.6 ºC.

A purpose of future works is to decrease heat losses and achieve larger temperature difference between heat exchangers.

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