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A VERSATILE MAGNETIC REFRIGERATION DEMONSTRATOR

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ABSTRACT — A versatile room temperature reciprocating magnetic refrigeration demonstrator has been designed, built and tested in order to check suitable magnetocaloric materials for magnetic refrigeration. Test experiments have been done with 31 g of Gd spheres of 0.2 – 0.4 mm diameter as refrigerant material, because it is a well-known benchmark material for magnetic refrigeration. The magnetic field is provided by a Halbach $Nd_2Fe_{14}B$ permanent magnet with a slot of 10 mm width and a maximum field of 1.4 T. At optimized values of frequency (f = 0.7 Hz) and utilization factor (U = 0.19), the demonstrator achieves a maximum no load temperature span of 19.3 K. A maximum cooling power of 6 W at zero temperature span was obtained at optimized values f = 0.31 Hz and U = 1.1. Different thermodynamic cycles have been studied looking for the optimized parameters.

1. INTRODUCTION

Magnetic refrigeration is a novel technology which is trying to be an alternative to conventional gas compression – expansion cooling systems. The main reasons to develop this technology are that is a more environmental friendly system because it does not use CFC gases and it is supposed to be more efficient, as reported by Gschneidner [1].

Many prototypes have already been built and tested successfully. Most of them are comprised of plates or spheres of gadolinium as an active refrigerant because is a well known benchmark material. Some of them are reciprocating test machines to test magnetocaloric materials, as can be seen in Richard et al [2], Bahl et al [3] and Tusek et al [4]. The rest are rotary prototypes which operate at high frequencies in order to obtain a higher cooling power, as can be seen in Tura and Rowe [5] and Lozano et al [6].

In this paper a versatile reciprocating magnetic refrigeration demonstrator to test active refrigerants is presented. The aim is to study the optimization of parameters and different thermodynamic cycles regarding the temperature span. Also the cooling power and coefficient of performance have been measured.

2. DEMONSTRATOR

A versatile magnetic refrigeration demonstrator has been built in order to check the magnetic refrigeration potential at room temperature. It uses 31 g of Gadolinium (spheres of 0.2 – 0.4 mm) as active refrigerant and a Halbach permanent magnet of $Nd_2Fe_{14}B$ as a magnetic field generator (1.4 T in a gap of 60×35×10 mm^3). The refrigerant liquid is water + 20% ethylene glycol. Several parameters can be modified in a broad range as the pushed fluid volume, mass flow and heat load. It is a first generation magnetic refrigeration system composed of a double active magnetic regenerator and characterized by a reciprocating motion of magnetization and demagnetization. The pumping system for the cooling fluid is composed of two adjustable pistons to push the refrigerant liquid through the regenerators. The cold side is placed between both regenerators, where there is an electrical heater in order to simulate a cooling power. There are two hot sides in the opposite sides of the regenerators. A complete temperature measurement system is installed in order to register the temperatures in the hot and cold sides, and inside each regenerator at 1/3 and 2/3 of its length. All this features can be seen in Fig. 1. The refrigeration system is based on a Brayton thermodynamic cycle, which is composed of four stages (adiabatic magnetization, hot blow, adiabatic demagnetization and cold blow).

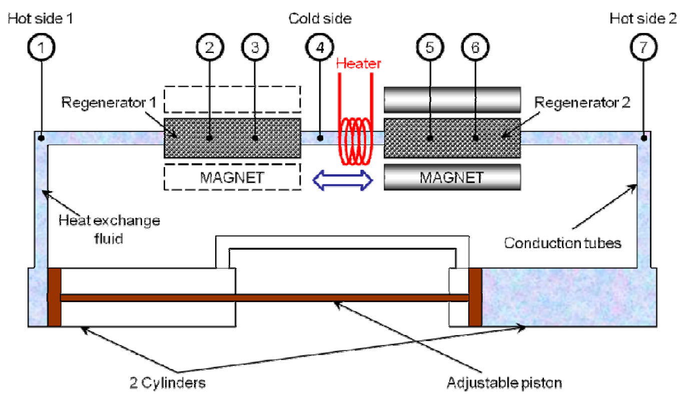

Fig. 1. Scheme of the magnetic refrigeration demonstrator. Temperature measurement points are indicated by numbers.

3. RESULTS

A large number of experiments have been done in an easy way by a batch of experiments changing the following parameters:

- Utilization factor: (0.1, 0.19, 0.29, 0.39, 0.49, 0.68, 0.88, 1.1) dimensionless.
- Mass flow: (0.26, 0.52, 1.04, 2.61) g/s.

- Heat load: (0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8) W.

Fig. 2 shows that a maximum no load temperature span of 19.3 K has been achieved, which means a regeneration ratio of 4.6. For every mass flow an optimum utilization factor (ratio of liquid to solid thermal capacity) of 0.19 was found, where the temperature span is maximum. Above this value the temperature span clearly decreases. It is also worth to observe Fig. 2 as a function of displaced fluid volume ratio relative to the available fluid volume inside the regenerator. The best volume ratios are observed from a minimum of 0.16 – 0.20, corresponding to the dead volume, up to 1. The upper limit of 1 indicates that the pushed fluid matches the interstitial volume, so higher values mix fluid from the cold and hot sides spoiling the behaviour.

A maximum cooling power of 6 W has been achieved, which means 190 W/kg. The correlation of temperature span – cooling power can be observed in Fig. 3. A linear dependence can be seen, as is widely shown for single material regenerators. As the utilization factor increases, the slope increases too and higher cooling powers are achieved, however, lower temperature spans are obtained at high cooling powers. Summarizing, high utilization factors are desirable when low temperature spans are demanded for the application and viceversa.

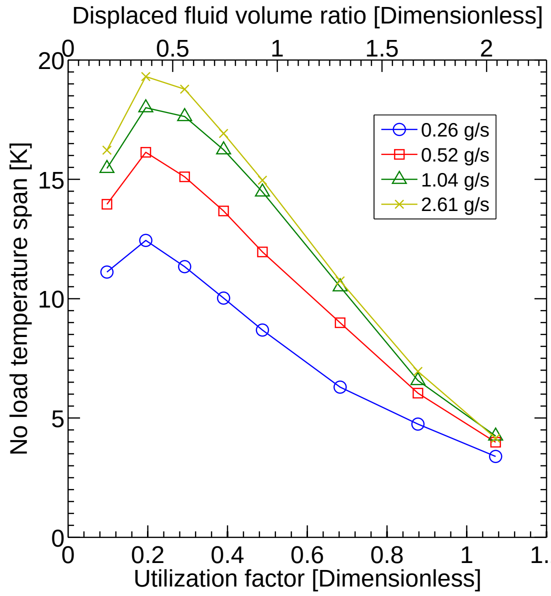

Fig. 2. No load temperature span as a function of utilization factor or displaced fluid volume ratio for several mass flows.

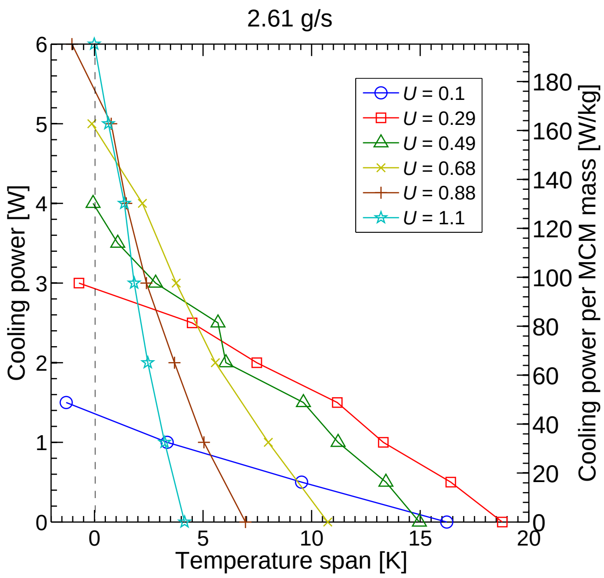

Fig. 3. Cooling power *vs.* temperature span for several utilization factors at a mass flow of 2.61 g/s.

4. Conclusions

A new versatile magnetic refrigeration demonstrator is presented. It is a first generation type based on a double active magnetic regenerator with a permanent magnet of 1.4 T. It has been built to show the feasibility of magnetic refrigeration technology and for a better understanding of the influence of different parameters. A maximum no load temperature span of 19.3 K has been achieved at U = 0.19 and mass flow of 2.61 g/s, and a maximum cooling power of 6 W (190 W/kg) at U = 1.1 and mass flow of 2.61 g/s. Frequency is a critical parameter for the magnetic refrigeration feasibility and needs to be increased for a practical use of this technology. The work done helps to advance in future scalable magnetic refrigeration prototypes regarding the efficiency and practical cooling powers without neglecting the temperature span. A magnet with a wider bore to introduce more magnetocaloric material and a third generation magnetic refrigerator to reach higher frequencies seems to be critical for the design of a useful prototype.

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