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Development and experimental results from a 1 kW prototype AMR

C.R.H. Bahl [a,*], K. Engelbrecht [a], D. Eriksen [a], J.A. Lozano [a,b], R. Bjørk [a], J. Geyti [a], K.K. Nielsen [a], A. Smith [a], N. Pryds [a]

[a] Department of Energy Conversion and Storage, Technical University of Denmark (DTU), Frederiksborgvej 399, DK-4000 Roskilde, Denmark

[b] POLO – Research Laboratories for Emerging Technologies in Cooling and Thermophysics, Department of Mechanical Engineering, Federal University of Santa Catarina (UFSC), Florianopolis, SC 88040-900, Brazil

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ABSTRACT

A novel rotary magnetic refrigeration device has been designed and constructed following the concepts recently outlined in Bahl et al. (2011). The magnet and flow system design allow for almost continuous usage of both the magnetic field and the magnetocaloric material in 24 cassettes, each containing an active magnetic regenerator (AMR) bed. The prototype design facilitates easy exchange of the 24 cassettes, allowing the testing of different material amounts and compositions. Operating with 2.8 kg of commercial grade Gd spheres a maximum no-span cooling power of 1010 W and a maximum zero load temperature span of 25.4 K have been achieved. For the purpose of actual operation, simultaneous high span and high performance is required. At a heat load of 200 W a high temperature span of 18.9 K has been obtained, dropping to a span of 13.8 K at the higher heat load value of 400 W.

Développement d'un prototype de régénérateur magnétique actif d'une puissance de 1 kW et résultats expérimentaux

Mots clés : Froid magnétique ; Régénérateur magnétique actif ; Dispositif magnétocalorique ; Gadolinium

1. Introduction

In recent years an increasing number of novel magnetocaloric devices have been designed, constructed and tested (see, e.g. Yu et al., 2010). The results and performance continually improve, inching the technology towards the regime of commercial implementation. The exact requirements for such a commercial device of course depend on the niche in which this technology will first break through. Some devices such as chillers or heat pumps require high cooling powers at modest temperature spans, while others, such as domestic refrigerators or freezers, require high temperature spans but

* *Corresponding author*. Tel.: +45 46775491; fax: +45 46775858.
E-mail address: chrb@dtu.dk (C.R.H. Bahl).
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less cooling power. For any application it will be imperative to optimise the device to fit the requirements set out.

1.1. *Classification of devices*

Traditionally magnetocaloric devices have been classified according to parameters such as the type of magnet (electro- or permanent magnet), morphology of regenerator (particles, spheres, wire meshes or plates) or type of heat transfer fluid (gas or liquid). The classification of devices into two types, rotary and reciprocating, is most consistently reported. However, as this property merely describes the relative motion of the magnet and magnetocaloric material it does not seem to be a defining property of a device. Devices with concentric Halbach type magnet assemblies that are rotated to modulate the field, see e.g. Tura and Rowe (2011), are termed rotary, while devices where a single Halbach type magnet assembly is moved back and forth, see e.g. Engelbrecht et al. (2009), are termed reciprocating devices. In actual fact two such devices may, except for this difference in the movement of the magnet, be built and operated in identical ways.

The motion of the heat transfer fluid after leaving the regenerator, seems to be a more distinguishing feature. Thus, the use of terms such as “modulating” and “continuous” (or uni-directional) to describe the fluid movement may prove more fundamental. In the modulating type the heat transfer fluid is pushed from the regenerator into the heat exchanger or volume containing the heat load and then the same fluid is pushed back into the regenerator in the next step of the AMR cycle. The devices presented in Tura and Rowe (2011) and Engelbrecht et al. (2009) are both examples of the modulating type. In the continuous type the heat transfer fluid is pumped through the regenerator and passes through the heat exchanger into another regenerator, always in the same direction. This type requires at least two regenerators to which the fluid flow can be controlled. The modulating type of device can either be of the reciprocating type (Zheng et al., 2009) or of the rotary type (Okamura et al., 2006). As the flow in the heat exchange circuit is unidirectional in the continuous type of device, an advantage is that the heat exchangers are not constrained to be directly adjacent to the regenerators, but can be placed some distance from them. In a real device this will be an advantage as it will allow more freedom in the design. Also, the dead volume fluid can be reduced in the continuous type of device, which is very important for the performance. Fig. 1 shows two different device designs that could both be called rotary but differ in the sense that (a) would in this classification be termed modulating while (b) would be termed continuous.

It should be noted that by modifying the valve and flow system of a device it is possible to change the device type. This has been done in Arnold et al. (2014), where modifications of the flow system including check valves have been applied to a system very similar to that in Tura and Rowe (2011), in order to get unidirectional flows in the heat exchangers.

1.2. *Design strategy*

In this paper we discuss the design and results of a device of the “continuous” type, similar to the one in Fig. 1(b). The device concepts have previously been described in Bahl et al. (2011). The regenerator consists of 24 separate compartments each operating its own AMR cycle. These are continuously rotated in the cylindrical bore of a concentric quadrupole magnet assembly. The eight regions of the magnet (four high field and four low field) each cover equal angular ranges of 45°. The magnet has been built as described in Bjørk et al. (2010) in order to maximise the field difference between the high and low field regions. A single pump at the hot end of the device pumps the heat transfer fluid unidirectionally around a circuit, first through a heat exchanger connected to a chiller, into regenerators in the low field regions, into the cold end where heat power is applied by an electrical resistance, into regenerators in the high field regions and back into the pump. Each opening of the flow circuit into the regenerator cylinder always covers more than one regenerator, so there is a continuous flow in the system, even during rotation.

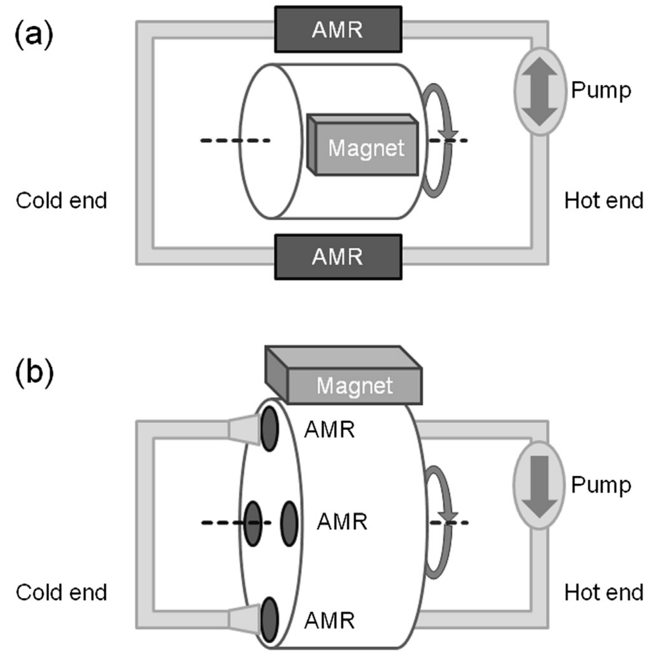

Fig. 1 – Two types of rotary devices. In (a) a magnet is rotated to magnetise two regenerators in an alternating way. This requires a modulating movement of the heat transfer fluid. In (b) four regenerators are rotated around in the presence of a magnetic field. The stationary flow system feeds the regenerators as they pass the openings. This allows for a uni-directional pump. By making the openings larger and increasing the number of regenerator beds, it is possible to ensure that the flow is always feeding at least one bed.

2. Experimental

The device is designed so that the 24 regenerator cassettes can be removed either as a set or individually. Two such sets of regenerators have been tested in the device. These were packed with two different amounts of Gd spheres from two different suppliers.