Applied Thermal Engineering 37 (2012) 388–395

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Numerical analysis of a reciprocating active magnetic regenerator made of gadolinium wires

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ARTICLE INFO

Article history:
Received 22 April 2011
Accepted 25 November 2011
Available online 8 December 2011

Keywords:
Magnetocaloric
Simulation
Active magnetic regenerator

ABSTRACT

During the last century, the MagnetoCaloric Effect (MCE) has been widely used for realizing extremely low temperatures. However, it is only in the last three decades that some of the efforts to develop a benign and cutting-edge technology for realizing the MCE at temperatures around room temperature have been realized. The main component of magnetocaloric systems is the Active Magnetic Regenerator (AMR), but it is difficult to realize an optimum design for the AMR because of the poor mechanical properties of the MagnetoCaloric Materials (MCMs).

In this study, an AMR configuration comprising a stack of gadolinium wires is investigated. A 1D physical model and a computer simulation program that can be used for studying the system are discussed in detail. The pressure drop, refrigeration capacity, Coefficient Of Performance (COP) and the exergy efficiency are numerically evaluated. Numerous simulation results obtained by using water as the working fluid for different regenerator geometries are discussed and optimal solutions are presented. These results are compared with those obtained for a configuration containing a bed of particles through which the working fluid flows.

1. Introduction

An AMR is a crucial component of magnetocaloric systems. It is a compact heat exchanger that functions as an active thermal source and a thermal regenerator, and it increases the temperature span and efficiency of the system. AMRs are usually made of only MCMs. MCMs have poor mechanical properties because of which the regenerator can only have a limited number of geometries. The comparisons performed by different authors (e.g., [1–3]) between different designs of regenerators showed some possible embodiments, e.g., a tube channel in a solid block, a stack of perforated plates arranged perpendicular to the direction of the heat transfer fluid flow, a stack of solid plates arranged parallel to the heat transfer fluid direction, a bed packed with spherical particles, and the different configurations of periodic corrugated lamellas. The embodiments containing plates demonstrate low friction losses but have a limited heat exchange surface area. In contrast, the particle bed configurations have a very large interface area, but a non-negligible pressure drop. The embodiments having a wavy structure demonstrate a good compromise between the degree of packing, heat exchange surface area, and friction losses, but the industrial production of these embodiments is not yet feasible since the mechanical treatment of MCMs is difficult.

Recently, the use of an MCM-particle bed with heat pipes has been considered by Egolf *et al.* [4]. This configuration solution permits small friction losses and has a large heat exchange surface area; thus, there is a possibility that such a solution will facilitate the realization of highly efficient magnetocaloric systems. While some simulation results are available, no experimental device has been tested yet. It appears that the complex manufacturing process and the resulting cost are the major drawbacks of this embodiment. Tura et al. [5] investigated a laser-sintered passive regenerator having square microchannels. However, the application of the principle behind this regenerator for fabricating an AMR made of MCMs has not been demonstrated yet.

A recent extensive literature review on numerical modeling of AMR can be found in Nielsen et al. [6]. Often an analytical mono-dimensional model is preferred to 2D and 3D model because of the prohibitive computation time.

In this study we propose to perform a parametric numerical study of a simple and original embodiment of AMR comprising a stack of gadolinium wires.

2. Model description

In this study, a rectangular regenerator consisting of a stack of MCM wires arranged parallel to the direction of the heat transfer fluid flow is considered (Fig. 1). The operation of the system (Fig. 2)

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doi:10.1016/j.applthermaleng.2011.11.053