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DEVELOPING A MAGNETOCALORIC DOMESTIC HEAT PUMP

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ABSTRACT — If the field of magnetocalorics is to progress beyond lab-scale demonstrations showcasing the technology at a small scale, it is important to develop prototype devices aimed at specific applications. Several groups and companies around the world are addressing cooling applications, including beverage coolers, A/Cs for cars and electronics cooling. Devices for heating have not been extensively demonstrated. Here we consider a promising application of magnetocaloric heat pumps for domestic heating. The task of designing and building such a device is a multidisciplinary one encompassing materials development and characterization, magnet design and construction, as well as device modelling, design and construction.

1. INTRODUCTION

Around the world a number of large scale interdisciplinary projects have been completed or are on-going. Examples of these are the EU seventh framework programme projects SSEEC and DRREAM, the Japanese NEDO financed project and the Danish MagCool project. The eventual success of a magnetocaloric device is critically dependent on the optimisation of each individual sub component (magnet assembly, magnetocaloric material performance and morphology, regenerator heat transfer and flow characteristics, etc.). Often optimisation of the individual components will lead towards contradicting conclusions. As an example, magnet performance is highest with the smallest pole gaps, but material requirements suggest maximising the volume and packing while pressure lowering suggests having a short porous regenerator in a large gap. Thus, the result is that no single component can be fixed considering the context of all other components. Interdisciplinary projects addressing all relevant areas concurrently will facilitate the compromises necessary to reach the best combination of components. The Danish MagCool project running from 2007 to 2011 aimed at doing this by addressing the permanent magnet design, AMR modelling and regenerator design, and successfully combining these to build a high performance prototype device [1], see Fig. 1.

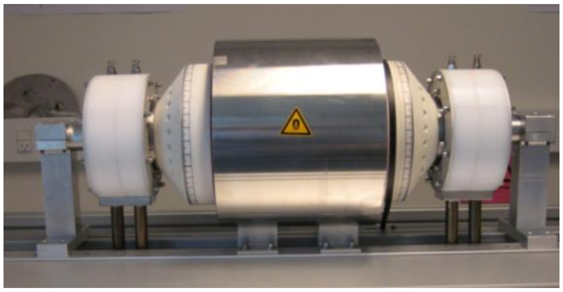

Fig. 1. Picture of the prototype device developed in the MagCool project. A cooling power of 200 W was reached at a temperature span of 19 K.

2. THE ENOVHEAT PROJECT

Building on the knowledge and experience gained in the MagCool project a large project to study the use of magnetocaloric devices as domestic heat pumps was applied for at the Technical University of Denmark and granted by the Danish Council for Strategic Research for the period January 2013 to July 2017. The project, "Efficient Novel Magnetocaloric Heat Pumps" (ENOVHEAT) has a target application of an efficient domestic heat pump with a heating power of 2 kW_{heat} with a relevant temperature span of about 30 K and a coefficient of performance (COP) of 5. Heat pumps powered by renewable power sources, such as wind, have been identified as a key route to reduce the CO_2 emissions from the domestic heating sector [2]. Fig. 2 schematically shows a magnetocaloric heat pump system, indicating the calculation of COP.

In the climate of Northern Europe the required power for heating a one family house can easily be more than 20 times that used for refrigeration and freezing appliances. Thus, any efficiency improvement from the use of magnetocaloric technology will be more valuable if applied to heating systems. Also, this expected increase in efficiency over conventional units should be enough to cover the higher initial investment cost associated with relatively large magnetocaloric units.

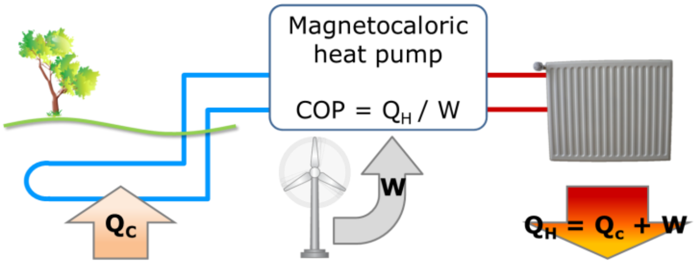

Fig. 2. The magnetocaloric heat pump will move the heat Q_C from a ground source to radiators or under-floor heating inside a house. The source of the work W is renewable energy from wind turbines.

A number of areas related to the study, development and utilisation of magnetocaloric heat pumps will be addressed:

- An area of focus will be to study the features that are exclusive to magnetocaloric heat pumps as opposed to refrigeration devices. An example is heat management. Any parasitic heating may be utilised instead of being detrimental. This will affect design decision and even allow the use of strategically placed electromagnets in the magnet assembly.
- Higher available entropy change makes first order phase transition materials potentially attractive for use as magnetocaloric materials. Indeed, they have been widely studied and characterised in lab conditions. However, there are often undesired properties such as thermal hysteresis, volume changes etc. which are challenging for application in devices. Studying and understanding these materials in working conditions will allow their utilisation in future devices.
- An area generally lacking in the work on magnetocaloric devices is system modelling and considerations on the installation and running of devices in real applications. As magnetocaloric devices have characteristics that are different from those found in conventional heat pumps, such an analysis is relevant and important in order to harness the full potential of magnetocaloric devices. It is important to consider requirements on the temperature spans, heating loads, response times, heat storage etc. Strategies for controlling heat pumps will also be addressed.
- Consolidation and shaping of the materials must be done in accordance with the properties of these to allow maximum usage of all the materials and a minimum flow resistance when passing through the regenerators. Accordingly, a suitable heat transfer fluid that will operate in the conditions required for a heat pump must be chosen.

The ENOVHEAT project brings together five universities: Technical University of Denmark, University of Southern Denmark, Aalborg University (Denmark), Imperial College (UK) and University of Ljubljana (Slovenia) as well as four industrial partners: Technoflex and Alpcon from Denmark and Vacuumschmelze and BSH Bosch und Siemens Hausgeräte from Germany. Each partner has specialist experience within the different areas of the project. For example the group at the Department of Technology and Innovation (ITI), University of Southern Denmark is contributing to the project with their expertise in the system modelling of various energy technologies and the group at the Department of Civil Engineering, Aalborg University is contributing with experience in energy management of low energy buildings.

Work in the project is split into three work packages (WP) each focussing on areas relevant for the design and construction of a heat pump. Each WP is built up around a number of PhD and postdoc projects focussing on the specific challenges.

WP 1: Materials and Magnets

PhD project: Materials for magnetocaloric regenerator

PhD project: Magnet assembly modelling and design

WP 2: System modelling and interface

PhD project: Dimensioning and incorporation into buildings

Postdoc project: Total system model

WP 3: Heat pump design and construction

Phd project: Design of magnetocaloric regenerators for heat pumps

Partial PhD project: Heat transfer fluids

Postdoc project: Design, construction and test of heat pump

Work on the ENOVHEAT project has commenced and each of the sub-projects has been initiated. A number of cross-WP milestones have been defined, to ensure the coherence of the work in each WP. More information about the project can be found at the project homepage: www.enovheat.dk.

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