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Title: *Numerical modeling of magnetocaloric cooler – a heat transfer analysis influenced by thermophysical properties of working fluid and structure of porous regenerator bed*

ABSTRACT

A research area presented in this doctoral dissertation is a modeling of the heat and fluid-flow phenomena occurring in a magnetocaloric cooler with an emphasis on an intensification of the heat transfer between a working fluid and a porous packed regenerator bed of a magnetocaloric material. The investigation included two research items affecting the intensity of heat transfer in cooler: an influence of thermophysical properties of working fluid as well as an influence of the different variants of porous bed's geometry.

At first two mathematical models were proposed to provide a specific description of the modeled system in a framework of Computational Fluid Dynamics. First model was dedicated for solving two-dimensional transient CHT (Conjugated Heat Transfer) problem while the second one was suitable for a three-dimensional steady-state single phase flow problem. The numerical domains in both models were defined differently – in a transient approach a system level model was proposed while the steady-state model was used for a component level analysis of porous packed bed chamber. In both cases a special, user-defined treatment of MagnetoCaloric Effect (MCE) was nested inside standard formulation of energy conservation equation as either source term for transient model or temperature boundary condition for steady-state model.

Transient system model was developed with reference to the twin experiment performed on the laboratory test stand of magnetocaloric cooling device. A main purpose of the conducted experiments was data aquisition required in both model build and validation processes. Temperature outputs extracted from thermocouples' locations (hot tank, cold tank) were collected in both physical and virtual investigations. An acceptable qualitative correlation level was found for steady-state temperature span (difference) between the hot and cold tanks.

Having validated the system model, the next step of dissertation focused on the thermophysical properties of working fluid and its impact on heat transfer magnitude. Simulations performed in this step were aligned with Design of Experiment approach which is also known as factorial study. The main principle of this research technique is observation of variation of output response caused by a deliberate manipulation of input factor values. In terms of presented analysis an influence of four thermophysical properties (density, specific heat, dynamic viscosity and thermal conductivity) - factors on two response variables (temperature span between tanks, available cooling capacity in cold tank) was assessed. A statistical analysis of results obtained in DOE included study of main effects, interactions effects, predictive

of significance for each factor was obtained. Factors with minor effect for temperature span response revealed greater importance with respect to available cooling capacity response

Previously mentioned steady-state model of fluid flow was applied to investigate heat transfer associated with different porous bed structures. The key assumption in CAD models preparation phase was processing of real bed geometry with the smallest possible degree of complexity reduction. The shapes of bed elements analyzed in this context included packed spheres, flat plates and cylinders. Last two types of geometries were oriented parallelly or orthogonally to the main flow direction. Apart from orthogonal cylinders all other geometries were tested in three cases with varying characteristic dimension (diameter or thickness). Pressure drop, heat flow accepted by fluid and ratio between the latter one and hydraulic power (product of pressure drop and flow rate) were chosen as performance metrics. All three quantities were collected against variation of working fluid flow rate.

Main practical conclusions from both research activities are listed below:

1. High thermal conductivity and low density are desirable when one would like to increase temperature span between hot and cold reservoirs. Interactions between all four thermophysical properties are not significant – the response is dominated by the main effects.

2. For available cooling capacity all four properties set on high level of value influenced response positively. Biggest impacts were noted for density and specific heat variations, respectively. Strong, nonlinear interaction effects played a non-negligible role in the transfer function between input factors and the response.

3. Packed beds filled with spheres allowed the highest amount of heat flow combined with moderate pressure drops. Orthogonally oriented cylinders were characterized with similar performance, which means it could be an attractive alternative to spheres. Concept of orthogonal plates indicated extremal results – compared to spheres it indicated nearly identical heat transfer behavior at the cost of the biggest pressure drop in the study. Two remaining groups of geometries (parallel plates and parallel cylinders) indicated smaller heat flow levels as well as pressure drops.

4. While designing or prototyping a porous regenerator bed one should try to elongate the fluid path i.e. increase the duration of time period in which fluid and solid bed could effectively exchange heat energy.

CFD toolset developed in this dissertation allowed to build significant engineering knowledge about working behavior of the analyzed system, acquired in a relatively short period of time within acceptable consumption of computational resources and preservation of the high fidelity of used numerical models. It is of utmost importance at the early, conceptual stage of the design process of magnetocaloric cooler prototypes. A modeling framework, such as the one presented in this research, might be a very efficient tool to evaluate multiple design iterations and select winning solutions to be furtherly worked on in the next steps. The models presented, especially the transient system model of the device, might be easily expanded by new simulation features in the future.

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