אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

לשכת המהנדסים
האדריכלים והאקדמאים
במקצועות הטכנולוגיים
בישראל
AEAi

The 35th Israeli Conference on Mechanical Engineering – ICME 2018
Beer-Sheva, 9-10 October 2018

Numerical investigation on sorption compressor thermal efficiency

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1. Abstract

Sorption compressors are thermally driven and do not have moving parts; therefore, they have the potential for long life and vibration-free operations. These benefits make sorption compressors attractive for space missions. The main drawback of sorption compressors is their relatively low efficiency, which is determined by a significant temperature distribution in the sorption cell and heat losses to the surroundings.

In the frame of our research on sorption compressors, we investigate different configurations of sorption cells. A numerical heat transfer model of the sorption compressor allows investigating the effects of geometry, materials, heating and cooling methods on the system efficiency.

Keywords: compressor, sorption, heat analysis

2. Introduction

Over the past few years, the interest in sorption compressors is increased, for space applications as well as for other applications. Nevertheless, their low thermal efficiencies are still a major drawback, which has to be improved [1-3]. Most reported systems are designed to be heated by an electric heater, and cooled by heat convection to the surroundings. In the current paper, we present a numerical model, which aims for optimizing the thermal design of a sorption cell. The model is one-dimensional [4] and suits axisymmetric configurations, which may consist of different materials and dimensions. The model allows to apply different techniques for heating and cooling the adsorbent material in the cell, and to consider the contact thermal resistances between materials in the cell. The model is validated against two published results [1,2], and preliminary thermal investigation results are presented. The model is nowadays further developed to comply with all the objectives mentioned above. It is the first phase of our research on sorption Joule-Thomson cryocooler for space applications, where a prototype shall be built and tested in our laboratory.

3. Methods

A numerical heat transfer model for cylindrical sorption cells is developed, using polar coordinates. Assuming large length over diameter ratios (greater than ten) [4], we define the heat transfer problem as a one dimensional, in the radial direction. The sorption cell consists of several axisymmetric materials, as shown in **שגיאה! מקור ההפניה לא נמצא.**. The cylinder is filled with an adsorbent, M1 and M3, where an electric heater, M2, has a helical shape and is installed inside the adsorbent space. The container consists of a metallic envelope, M5, with two insulation layers, M4 and M6. The model allows changing all dimensions, and it is possible to eliminate any material by applying zeroth thickness.

A transient finite elements technique is used to describe the sorption cell, implemented by a MATLAB code. Every material is divided to elements with a single node at the middle of each element, at radius $r_m(i)$, where i is the index of the element. Every element is specified by a temperature dependent specific heat capacity, c_p, a conductive heat transfer coefficient, k, and a density, ρ. In addition, each element have an internal heat generation parameter, q_{gen}, see Figure 2. Every element is defined as a "lumped capacity" and the element energy is time dependent. R_m^+ and R_m^- are the thermal resistances in the growing radius and the opposite directions, respectively.

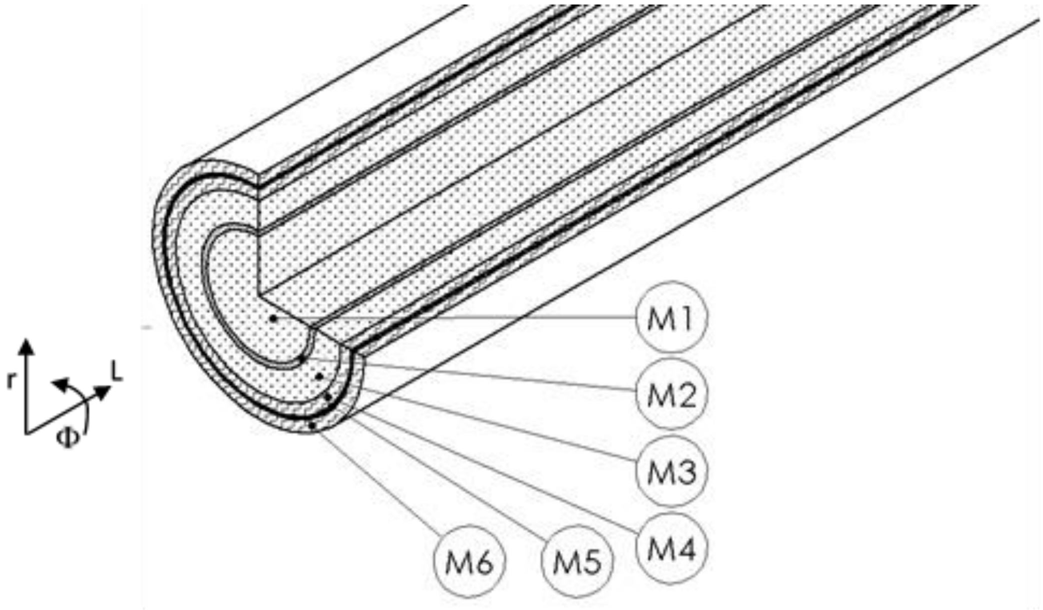

Figure 1. Sorption compressor general view

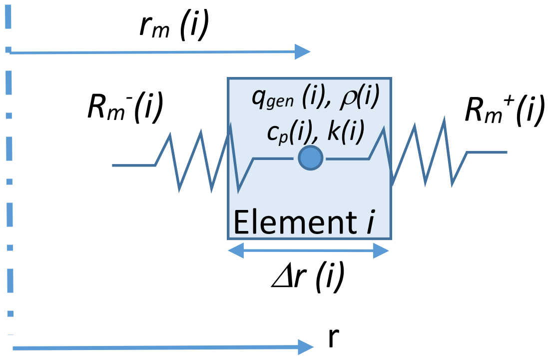

Figure 2. A general description of an element

The motivation of this study is to improve the efficiency of the adsorption compressor; therefore, a parameter TESC (non-dimensional) is introduced. This parameter defines the ratio between the energy transferred to the adsorbent material (excluding all other materials of the sorption cell) to the invested heat energy. TESC is time dependent and it is determined as follows:

$$TESC(\mathcal{T}) = \frac{\sum_{i=1}^{Ns}\left[\left(T_i^n - T_i^0\right) \cdot 2\pi \cdot L \cdot r_{m,i} \cdot \Delta r_i \cdot \mathrm{C}_{p,i} \cdot \rho_i\right]}{\mathrm{P}_{in} \cdot \mathcal{T}}$$

Where T_i^n is the temperature at time step n, T_i^0 is the initial temperature of element i, P_{in} describes the input power to the system, Ns is the number of sorbent elements, $\mathcal{T}$ is the time, and L is the length of the sorption cell.

RESULTS & DISCUSSION

At this stage of the study, we investigated the heating efficiency of different heaters, which are specified in table 1. In the current case study, the sorption cells consist of M1, M2, M3, and M5, only, while both insulation sections, M4 and M6, are eliminated. The total volume of the adsorbent material, the heater volume, and the cell envelope volume are maintained constant. The length of the cylinder cell is also maintained constant, and equals 0.2 m. The inner radius of the sorption cell is 8 mm. The envelope thickness of the sorption cell is determined by the minimum allowed thickness, multiplied by a safety factor of four. The initial temperature of each section is 300K, and 100W electric heating power is applied for 30 seconds. Table 1 shows the outer radius of sections M1, M2, and M3, for the different heaters. Table 2 shows the different material properties. In order to determine an optimal thermal performance, the temperature distribution and TESC is explored for each heater. Figure 3 illustrates the temperature distribution at 30 seconds for the different heaters, and Figure 4 shows the TESC as a function of time. Among the heaters which are examined in the current study, heater 3 shows the best performance. Heater 1 provides the highest temperature in the sorbent material, in comparison to the other heaters; however, it also creates the largest temperature gradient on the radial direction. Helical heaters create lower absolute temperatures with better temperature uniformity in the cell.

Table 1: heater dimensions

Heater name	Outer radius M1 (mm)	Outer radius M2 (mm)	Outer radius M3 (mm)
Heater 1	0	1	8
Heater 2	2	2.24	8
Heater 3	4	4.13	8
Heater 4	6	6.09	8
Heater 5	7.94	8	8

Table 2: material properties

Property	M1 + M3	M2	M5
k (W/mK)	0.2	19	20
c_p (J/kgK)	1000	500	500
ρ (kg/m^3)	450	8000	8000

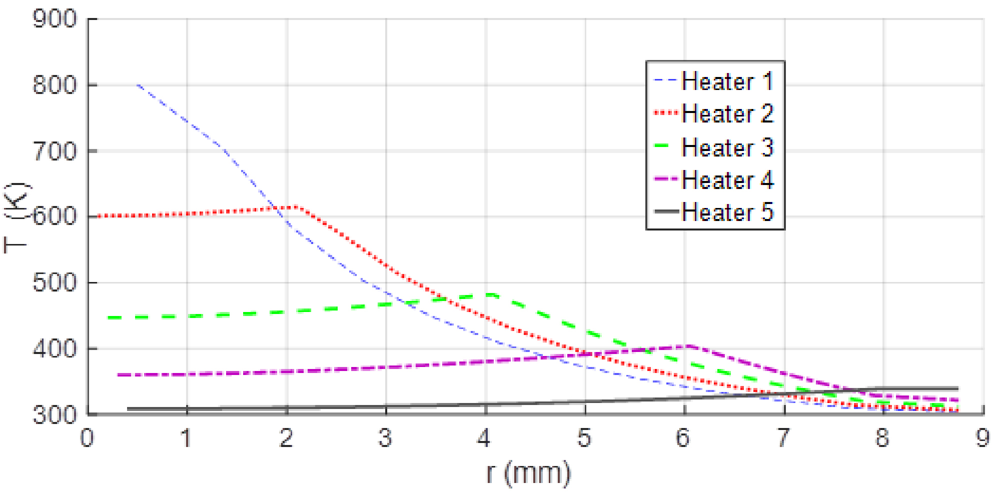

Figure 3. Temperature distribution at 30 sec, for the five different heaters

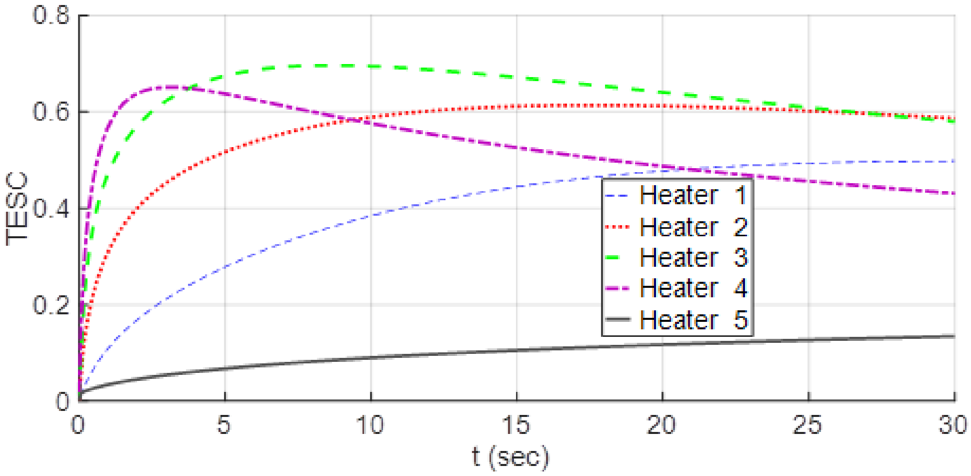

Figure 4. TESC as a function of time, for the five different heaters

4. Conclusions

A one-dimensional thermal model has been developed, to analyze the performance of sorption compressor cells. The model is successfully validated against numerical and experimental published results. TESC parameter is suggested and explored for optimizing the design of sorption cells. The case study which is presented here refers to five different heaters in a simple cylindrical sorption cell, without any insulation layers. This preliminary study shows that an optimal design exists and can be determined. We continue our research to further improve the model and to investigate more configurations of sorption cells.

5. References

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