Numerical optimization of a multistage sorption compressor

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Abstract. Sorption compressors are driven by thermal cycles and have no moving parts, excluding some passive check valves. Such compressors are suitable for powering Joule-Thomson (JT) cryocoolers and can provide reliable and vibration free active cooling system with a potential for high reliability and long operating life. The thermal cycle consists of cooling and heating a sorbent material which is installed in a sorption cell, where the heating is obtained by an inner electric heater and cooling is obtained by the surrounding via the sorption cell envelope. The investigation and optimization of the sorption cells were conducted in previous work, at steady state conditions, by a one-dimensional heat and mass transfer numerical model. The current paper presents a dynamic numerical model of sorption compressors which consist of several sorption cells. The numerical model allows one to three compression stages, with any number of sorption cells at each stage. The model enables the investigation of dimensional parameters and operational parameters, and provides the low and high pressures, pressure fluctuations, and compressor’s efficiency. The current investigation focuses on a three-stage compressor for nitrogen, with low and high pressures of 0.2 and 8 MPa, respectively, and a mass flow rate of about 11 mg/s.

1. Introduction
A sorption compressor consists of a one or more sorption cells which are thermally driven without moving parts, except for some check valves. Therefore, sorption compressors don’t emit vibration and noise, and they have the potential for long life and high reliability [1,2]. A general cycle of a sorption cell is presented in figure 1 and consists of four processes: (1) heating with valves closed, (2) heating with discharge valve open, (3) cooling with valves closed, and (4) cooling with intake valve open. Figure 1(a) shows the pressure in the cell as a function of time, and figure 1(b) shows the cycle on an adsorption concentration versus pressure plane.

In a previous work [3,4] we investigated the design of sorption cells to obtain high efficiencies as well as high specific power of the cells, at steady state conditions. In the current research, we numerically investigate a complete multi-stage sorption compressor, by a fully parametric dynamic model, of seven sorption cells, which are electrically heated and cooled by the surrounding via a gas gap heat switch [5]. Dimensional parameters are the sorption cell dimensions, buffer and intercooler volumes, and flow restriction. Operational parameters are the filling pressure, desired mass flow rate, ambient temperature, heating power, and heating duration. The model provides the low and high pressures, pressure fluctuations, and compressor’s efficiency. The research focuses on a three-stage compressor for nitrogen, with low and high pressure of 0.2 and 8 MPa, respectively, and a mass flow rate of about 11 mg/s.
2. Method
Figure 2 shows a schematic view of a three-stage compressor which is developed in the frame of the current research. The first compression stage consists of sorption cells 1 – 4, the second compression stage consists of sorption cells 5 and 6, and the third compression stage consists of sorption cell 7. Intercoolers ‘a’ and ‘b’ are installed between the stages to bring the fluid temperature back to the ambient temperature after compression. A low pressure buffer and a high pressure buffer are installed to reduce the pressure fluctuations and a restrictor provides the flow resistance in the system.

The numerical model, which is implemented by a Matlab® code, is time dependent and integrates numerical codes of individual sorption cells [3], taking into consideration all the connecting features; intercoolers, buffers and the flow restriction. The model is fully parametric, meaning, all the physical dimensions and the operating conditions can be determined by the user. The initial conditions are provided mainly by the filling pressure, and the operating parameters are provided by the heating power and heating duration. The compressor performance is obtained by the model, both during the transient process and at a steady state.

Figure 1. Full cycle of a sorption cell at a steady state operation. (a) cell pressure versus time, (b) adsorption concentration versus temperature and pressure.

Figure 2. A three-stages sorption compressor model.
3. Results
Figures 3 and 4 show the results of two sorption compressor runs with different filling pressures and high pressure buffer volumes, while all other operating and physical inputs are identical. Both cases aim for low and high pressures of 0.2 and 8 MPa, respectively, and a flow rate of 11 mg/s. Figure 3 presents the results of a filling pressure equals 1.67 MPa, and a high pressure buffer volume of 3.0 L, and figure 4 presents the results of a filling pressure equals 0.86 MPa and a high pressure buffer volume of 0.8 L. The main difference between the two cases is expressed by the transient process duration, and the high pressure fluctuations. A small volume of the high pressure buffer provides relatively high pressure fluctuations and a quick attainment of a steady state. The results in figures 3 and 4 also provides the pressures at the intercoolers and allows the determination of the heating power and duration.

The intermediate pressures in figure 3 are 0.57 and 2.00 MPa, and in figure 4 they equal 0.57 and 2.06 MPa. The pressure ratios of the three compression stages are 2.85, 3.51 and 4.00 in figure 3, and 2.87, 3.59 and 3.89 in figure 4. One shall notice that unlike mechanical multi-stage compressors, the pressure ratios of the stages are not identical, and moreover, they can vary due to changes in the sorption compressor design. This result emphasis the significance of an adequate model of a sorption compressor.

![Figure 3](image1.png)
**Figure 3.** Numerical results of a three-stages compressor, with a filling pressure equals 1.672 MPa and a high pressure buffer of 3 L.

![Figure 4](image2.png)
**Figure 4.** Numerical results of a three-stages compressor, with a filling pressure equals 0.86 MPa and a high pressure buffer of 0.8 L.
Figure 5 shows the filling pressure, high pressure fluctuations, and the time to steady state as functions of the high pressure buffer volume. Increasing the volume of the high pressure buffer decreases the high pressure fluctuations and increases both the time to steady state and the filling pressure. These trends are quite predicted, however, the actual performances can be determined only with a detailed simulation, such as presented herein. For a given system, once it is filled (with a filling pressure), the performances are determined by the heating power and duration, assuming constant ambient conditions. If the ambient conditions are changed as well, the model allows to control the system for obtaining stable performances.

4. Conclusions
This paper presents a dynamic numerical simulation of a three-stages sorption compressor operating with nitrogen. A few results are presented to demonstrate some of the model capabilities. The model is developed to determine the performance of a complex system of several sorption cells, which are connected in series and in parallel, and activated in phase shifts. The numerical model is essential for designing a sorption compressor and it successfully serves our researches on sorption compressors for different applications.

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