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Design of a bench-scale ammonia-SrCl₂ thermochemical storage system using numerical modelling

Saman Nimali Gunasekara¹, Michail Laios¹, Anastasiia Karabanova², Viktoria Martin¹ and Didier Blanchard²

¹Department of Energy Technology, KTH Royal Institute of Technology, Brinellvägen 68, SE-100 44, Stockholm, Sweden. Phone: 46 73652 3339, 46 76563 5044, 46 8790 7484, e-mail: saman.gunasekara@energy.kth.se; laios@kth.se; viktoria.martin@energy.kth.se
²Department of Energy Conversion and Storage, Technical University of Denmark, Frederiksborgvej 399, P.O. Box 49, DK-4000 Roskilde, Denmark. Phone: 45 4677 5899, 45 7183 6790, e-mail: dibl@dtu.dk; anaka@dtu.dk

Abstract

This work presents the numerical modelling of a bench-scale thermochemical storage (TCS) system based on the reversible absorption-desorption of ammonia in strontium chloride. The modelling is performed using the ASPEN software and was validated against experimental data from literature on a different TCS system configuration but using the same reaction pair. The modelled TCS system in this work comprises two identical reactors, alternatively operating as absorber or desorber with a storage capacity of 0.5 kWh. The system is designed to store and release heat under 8 bar of NH₃ pressure, with the two identical reactors respectively undergoing desorption at 82 °C and absorption at 79 °C. Together with the two reactors, a liquid ammonia storage tank is used as a buffer (10 bar at 25 °C). The desorption half-cycle of the system is made of the desorber (82 °C, 8 bar), a compressor (8-10 bar), a cooler (108-25 °C), a pump (to pump liquid ammonia) and the liquid ammonia storage (25 °C, 10 bar). The absorption half-cycle starts form the liquid ammonia storage tank and goes via an expansion valve (10-8 bar) and then a heater (18-25 °C) towards the absorber (79 °C, 8 bar). In the model, the desorption and absorption are respectively driven by an external heater and cooler, which represent a waste heat source and a heat sink respectively. The efficiency of the TCS system was found to be of 67 % and 61 % for the absorption and desorption half-cycles, respectively. A sensitivity analysis was also conducted to identify optimum operating conditions. In conclusion, this study presents an ammonia-SrCl₂ TCS bench-scale system that allows simultaneous heat storage and retrieval, as the basis for the practical construction of the system. This is expected to provide inspiration and operational analysis to accommodate the design of similar TCS systems for storing surplus industrial heat.

Keywords: thermochemical storage (TCS), NH₃-SrCl₂ system, absorption, desorption, numerical modelling, Aspen

1 Introduction

Thermal energy storage (TES) is an essential part in today’s energy system management to combat climate change, allowing improved efficiencies, renewable energy sources integration and mitigation of fossil fuels-based CO₂ emissions. TES brings attractive advantages through peak shaving and load shifting [1], [2], and by balancing the time and locational mismatch between thermal energy supply and demand [3], [4]. Thermochemical heat/cold storage (TCS) is one compact TES alternative with the potential to provide storage densities up to 5 times
larger than the state of the art phase change materials (PCMs), or up to 25 times the one of sensible TES [5]. TCS involve physical endo/exo-thermic processes like adsorption, or chemical processes through reversible chemical reactions (via absorption/desorption).

One of the most-investigated adsorption-based TCS systems today uses water as adsorbate on zeolite as adsorbent [6]-[9]. The majority of TCS systems involving chemical reactions also primarily employ water as absorbate and salts as absorbents, forming salt hydrates from compounds such as MgCl$_2$ [8], [10]-[12]; CaCl$_2$ [10]-[15]; MgSO$_4$ [10], [12], [15]; MgCl$_2$ [15], [16]; SrBr$_2$ [8], [11], [12]; Na$_2$S [8], [17]; NaOH [8], [18], [19]; LiBr [13], and Al$_2$(SO$_4$)$_3$ [10], or salt hydroxides such as Ca(OH)$_2$ (from CaO) [20]-[22]. These water-based systems can be designed as opened or closed configurations since water is not hazardous.

Chemical reactions-based TCS systems using other absorbates than water require closed system operation since the employed absorbates (fluid) should not be directly released to the atmosphere. Among such TCS designs, numerous systems involve the reaction pair NH$_3$ (absorbate) and a metal halide (absorbent) such as [23], SrCl$_2$ [24]-[30], MnCl$_2$ [31]-[34], CaCl$_2$ [34], [35], BaCl$_2$ [32], [36], MgCl$_2$ [37], and NH$_4$Cl [33]. These systems offer higher energy storage densities than the water-based systems and more flexibility in the system operating pressures. Some of these NH$_3$-metal halide TCS systems are also designed with two respective salts for low-temperature (LT) and high-temperature (HT) cycles, using e.g. BaCl$_2$ and MnCl$_2$ [32], NH$_4$Cl and MnCl$_2$ [33], CaCl$_2$ and MnCl$_2$ [34], [38], and two different ammines of CaCl$_2$ [35]. A majority of these NH$_3$-Metal halide TCS systems utilize the gas-solid reaction (e.g. [25]-[34], [37], [38]) while some also consider the reaction between solid-liquid (e.g. [28]). Many of these designed TCS systems consist of a single reactor that operates in batch-mode, alternatively storing and releasing heat with NH$_3$ desorption and absorption, respectively (e.g. [25], [28], [29], [31], [37]). Whereas, some other NH$_3$-metal halide TCS designs comprise two separate reactors for simultaneous absorption and desorption, either for the same reaction pair [26], [27], or for different reaction pairs for the LT and HT cycles respectively, containing two different salts [32]-[34], [38], or two different ammines [35]. Most of these systems maintain the solid absorbent within the reactor, but a few transport the solid absorbent, e.g. in powder form between the absorber and desorber [26].

This work is part of a project within a Nordic collaboration: Neutrons for Heat storage (NHS) [39]. The NHS project leaders at DTU, Denmark, have already constructed a bench-scale single reactor TCS system for the NH$_3$-SrCl$_2$ reaction pair [29] and use neutron imaging, radiography and tomography, to improve the reactor design and therefore the efficiency of the whole TCS. The project partners at KTH, Sweden, aim to design a bench-scale TCS system to simultaneously store and release low-temperature heat at 40-80 °C using the same NH$_3$-SrCl$_2$ reaction system. A bench-scale system was chosen as a sufficient representation of the behavior of a real-life application system (unlike at laboratory-scale), while still being economical in construction. The experimental analysis of this bench-scale TCS system is then expected to yield important design implications for the scaling-up of the system to e.g. pilot-scale, and provide valuable experimental data on e.g. the reaction kinetics. Inspired by the findings on the TCS system at DTU as well as from literature, the current work aims to develop the preliminary design of this TCS system using ASPEN Plus numerical modelling [40] to accommodate simultaneous heat storage and retrieval around 80 °C using two identical reactors with a storage capacity of 0.5 kWh each.

2 Methodology

Here, the theoretical background, the conceptual design of the chosen TCS system, and important aspects and assumptions regarding modelling the system using Aspen Plus [40] are presented.
2.1 Operating principle

The reaction pair NH₃·SrCl₂ undergoes two main reaction steps as displayed in Eqn. 1 and Eqn. 2, to achieve the complete transformation from pure SrCl₂ to its octaammine (SrCl₂·8NH₃), as expressed in Eqn. 3. Here, ΔH denotes the respective reaction enthalpy for each case, where absorption is an exothermic reaction and desorption is endothermic. In this work, only the specific reversible chemical reaction between the monoammine (SrCl₂·NH₃) to octaammine, (Eqn. 2) are considered because it fulfills the desired working temperature/pressure conditions.

\[ \text{NH}_3(g) + \text{SrCl}_2(s) \rightleftharpoons \text{SrCl}_2\cdot\text{NH}_3(s) + \Delta H \quad \text{Eqn. 1} \]
\[ 7 \ \text{NH}_3(g) + \text{SrCl}_2\cdot\text{NH}_3(s) \rightleftharpoons \text{SrCl}_2\cdot8\text{NH}_3(s) + \Delta H \quad \text{Eqn. 2} \]
\[ 8 \ \text{NH}_3(g) + \text{SrCl}_2(s) \rightleftharpoons \text{SrCl}_2\cdot8\text{NH}_3(s) + \Delta H \quad \text{Eqn. 3} \]

The enthalpy and entropy of the reaction between the monoammine and octaammine are respectively 41.4 kJ/mol NH₃ and 230 J/(mol·K) [41], i.e., involving seven ammonia molecules per molecule of salt. Whereas, the enthalpy and entropy values for the last ammine are 48.1 kJ/molNH₃ and ~230 J/(mol·K) [41]. Thus, the reaction of the last ammine is the most energetic step and requires, for its desorption, either a too high temperature (> 150 °C at ~8 bar) or a very low pressure (> 670 mbar, at 80 °C) [29]. In addition, during this reaction step, the salt undergoes the largest volume change per ammine (125%), a change detrimental for the system [29]. Therefore, this TCS system design excludes the conversion of the last ammine, and is thus restricted to the reaction between SrCl₂·NH₃ and SrCl₂·8NH₃ (Eqn. 2).

For a heat storage capacity of 0.5 kWh, the calculation of the amounts of NH₃, SrCl₂·NH₃ and SrCl₂·8NH₃ needed for the stoichiometric reaction is explained in Eqn. 4-Eqn. 9 (where, the molar masses of NH₃, SrCl₂·NH₃ and SrCl₂·8NH₃ are 17.03 g/mol, 175.55 g/mol, and 294.77 g/mol respectively).

\[ 0.5 \text{ kWh} = 0.5 \text{kJ/s} \times 3600 \text{s} = 1800 \text{ kJ} \]

For 1 mole of NH₃, the required moles of SrCl₂·NH₃ = 1/7 molSrCl₂·NH₃

\[ \text{SrCl}_2\cdot\text{NH}_3(s) \rightarrow \text{SrCl}_2\cdot8\text{NH}_3(s) \] conversion enthalpy = 41.4 kJ/molNH₃

\[ \text{NH}_3(g) + \text{SrCl}_2\cdot\text{NH}_3(s) \rightleftharpoons \text{SrCl}_2\cdot8\text{NH}_3(s) + \Delta H \]

To store 0.5 kWh, the amount of NH₃ needed = \( \frac{1800 \text{ kJ}}{41.4 \text{ kJ/molNH₃}} = 43.48 \text{ gNH₃} \)

Thus, the amount of SrCl₂·NH₃ needed = 6.21 molSrCl₂·NH₃ = 1090.38 gSrCl₂·NH₃

The amount of SrCl₂·8NH₃ needed 6.21 molSrCl₂·8NH₃ = 1830.86 gSrCl₂·8NH₃

The progression of the reaction (Eqn. 1-Eqn. 3) depends on the pressure and temperature. This reaction system’s equilibrium pressure depends on temperature, and can be expressed using the Van’t Hoff’s equation, as in Eqn. 10 [29], [41]. Here, \( p_{eq} \) is the equilibrium pressure (Pa), \( p_0 \) is the reference pressure equal to 1 Pa, \( \Delta H \) and \( \Delta S \) are respectively the reaction enthalpy (J/mol) and entropy (J/(mol·K)), \( T \) is the reaction temperature (K) and \( R \) is the ideal gas constant (8.314 J/(mol·K)).

\[ p_{eq} = p_0 \times \exp\left(\frac{-\Delta H}{RT} + \frac{\Delta S}{R}\right) \quad \text{Eqn. 10} \]

The specific operating temperatures and pressures are chosen for both absorption and desorption around 80 °C (the upper margin of the range 40-80 °C). This was done by referring to the equilibrium pressure-temperature curve of the NH₃·SrCl₂ system, for the conversion between SrCl₂·NH₃ and SrCl₂·8NH₃. This is plotted (based on the Van’t Hoff equation, in Eqn. 10) together with the phase diagram of NH₃ in Figure 1. As Figure 1 indicates, the equilibrium pressure for this TCS system at 80 °C is 7.73 bar. That is, to accommodate absorption, the
system should be maintained above 7.73 bar at 80 °C, whereas for desorption it should be maintained below 7.73 bar. Therefore, this condition is chosen as the marginal condition between the two reactions, for this TCS system design work.

\[
\text{Pressure (bar)} \\
\begin{array}{c|c|c|c|c|c|c}
\text{Temperature (°C)} & 0 & 10 & 20 & 30 & 40 \\
\hline
\text{NH}_3 \text{ liquid} & 4 & 8 & 12 & 16 & 20 \\
\hline
\text{NH}_3 \text{ vapor} & 20 & 30 & 40 & 50 & 60 \\
\hline
\end{array}
\]

2.2 Conceptual design and numerical modelling with Aspen Plus

Based on the equilibrium condition of SrCl\(_2\)-NH\(_3\) and SrCl\(_2\)-8NH\(_3\) system at 80 °C and 7.73 bar, for operational simplicity, the reaction pressure was chosen to be at 8 bar. For this 8 bar reaction pressure, it was chosen to maintain absorption at 79 °C (\(P_{eq}=7.42 \text{ bar} < 8 \text{ bar}\)) and desorption at 82 °C (\(P_{eq}=8.37 \text{ bar} > 8 \text{ bar}\)) in agreement with Figure 1. The storage of NH\(_3\) is more cost-effective in liquid state. Therefore, to be able to store NH\(_3\) in liquid-state at room temperature (at or below 25 °C), it was decided to maintain NH\(_3\) at 10 bar, according to the NH\(_3\) phase diagram in Figure 1. To accommodate simultaneous absorption and desorption in these conditions, the conceptual design of the TCS system is established as in Figure 2. As Figure 2 shows, the TCS system contains two identical reactors for alternating absorption/desorption reaction (as indicated by the dashed lines).

For a given reaction half-cycle, NH\(_3\) gas that is desorbed at 8 bar is compressed to 10 bar (the NH\(_3\) storage pressure) using a compressor. The temperatures of some of the streams (e.g. the outlets of the desorber, compressor, evaporator, external heater and external cooler, as well as the inlet of the external heater) are unknown and expected to be found through the numerical modelling. As the compression will heat-up NH\(_3\), it is then cooled to 25 °C by the cooler, into liquid-state at 10 bar, and is then pumped to the NH\(_3\) storage tank. This stored NH\(_3\) is then used in absorption, by expanding to 8 bar (with eventual cooling), heating back to 25 °C (by the heater) thus converting it into gas, and then sending into the absorber at 8 bar and 79 °C.
absorber and desorber will be maintained at these desired temperatures using an electrically operated external cooling and heating source respectively.

This conceptual design of the system is then modelled using ASPEN Plus (V9) [40]. The simulation identify all the inlet and outlet conditions and the optimal operating conditions. The model was validated against experimental data from literature on a different TCS system configuration but using the same reaction pair [25]. A sensitivity analysis was also performed on the current ASPEN-based system to analyze its optimal operating conditions.

For modelling the TCS system in ASPEN, the flow rates of materials are required. These rates (0.01087 mol\(\text{NH}_3\)/s, and 0.00155 mol/s respectively of \(\text{SrCl}_2\cdot\text{NH}_3\) and \(\text{SrCl}_2\cdot8\text{NH}_3\)) are obtained by dividing the respective amounts of \(\text{NH}_3\), \(\text{SrCl}_2\cdot\text{NH}_3\) and \(\text{SrCl}_2\cdot8\text{NH}_3\) in the system (43.48 mol\(\text{NH}_3\) and 6.21 mol respectively of \(\text{SrCl}_2\cdot\text{NH}_3\) and \(\text{SrCl}_2\cdot8\text{NH}_3\)), by the reaction time: 4000 s. This time was chosen based on the semi-empirical absorption and desorption times, 4000 s and 3000 s reported by Nagamalleswara Rao et al. [27] (derived using experimental data from Huang et al. [24]) for the same reaction pair and similar amount of salt (1 kg). Accordingly, to ensure complete transformation even during the slower reaction (i.e., desorption), 4000 s was chosen here for both reactions. In ASPEN, an RGibbs reactor was selected [40] as the most suitable type for this reaction process. Inherently, ASPEN software does not allow a reactor to contain reactants or products inside the reactor in batch-mode, but instead, requires a continuous in- and out-flow of all reactants and products. Due to this limitation, unlike the real reactor that maintains the salts inside the reactor, in the model, the reactants are sent in while the products are sent out from the reactors, continuously. That is, in the ASPEN model, using the derived flow rates, \(\text{NH}_3\) and monoaamine are sent into the absorber while octaamine is sent out, and vice-versa in the desorber. Consequently, as the outlet stream of the desorber contains a mixture of \(\text{NH}_3\) and \(\text{SrCl}_2\cdot\text{NH}_3\), \(\text{NH}_3\) gas is separated from the solid \(\text{SrCl}_2\cdot\text{NH}_3\) in a separator, because it is only \(\text{NH}_3\) that should be circulated towards the rest of the system. This feature appears only in the model, as for the real system this separator is unnecessary (because there, the solid salt always remains inside the reactor). These streams are however still within the system boundary, and thus can still correctly represent the real system’s operation in ASPEN.

In this work, heat losses and pressure losses in the system were neglected, while \(\text{NH}_3\) leaving the cooler and the evaporator (expansion valve) is respectively assumed to be saturated and superheated. The external heater and cooler were chosen to be the model 1166D from VWR (with heating and cooling capacities, and total volume being 2.2 kW, 0.1-0.2 kW (for -10 to 20 °C) and 6 l) [43], with the heat transfer fluid (HTF): Therminol 66 [44].

### 3 Results and discussion

The final design of the \(\text{NH}_3\)-\(\text{SrCl}_2\) TCS system for the simultaneous absorption and desorption (between \(\text{SrCl}_2\cdot\text{NH}_3\) and \(\text{SrCl}_2\cdot8\text{NH}_3\)) in ASPEN is shown in Figure 3, and the corresponding real system is shown in Figure 4. As explained, the real system in Figure 4 excludes the separator as it retains the solid salt always within the reactors. The calculator blocks in the ASPEN model, in Figure 3, mathematically match the heat duties of the external heating/cooling sources with those needed to maintain the respective temperatures in the reactors. The results yielded the unknown temperatures of the system’s various streams, now combined into Table 1, detailing the operating conditions of all the streams in the system (the data from simulations in bold). The inlet temperature of the HTF from the external heater was chosen as 88 °C, assuming a 6 °C temperature gap between the reactor and the HTF is sufficient to encourage the desired heat transfer. The modelled TCS system can therefore operate at around 80 °C as desired, storing heat at 82 °C in the desorber, and releasing the stored heat at 79
6°C in the absorber, each at 8 bar. After all, maintaining a temperature at an exact set point is practically difficult, and therefore these operating temperatures will be achieved in a range, in the practical system.
Figure 3. The Aspen model of the NH₃-SrCl₂ TCS system for the simultaneous absorption and desorption. (COMPRESS: compressor, SEPARAT: Separator, STORAGE: NH₃(l) storage, EXPANVAL: Expansion valve, HEX1: external heater, and HEX2: external cooler)

Table 1. The detailed operating conditions of the designed TCS system in the Aspen model (in **bold** are the conditions found through Aspen simulations)

<table>
<thead>
<tr>
<th>Component</th>
<th>Desorber</th>
<th>Compressor</th>
<th>Cooler</th>
<th>Pump</th>
<th>NH₃(l) storage</th>
<th>Expansion valve</th>
<th>Heater</th>
<th>Absorber</th>
<th>External heater</th>
<th>External cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet T (°C), P (bar)</td>
<td>82, 8</td>
<td>82, 8</td>
<td>108, 10</td>
<td>25, 10</td>
<td>25, 10</td>
<td>25, 8</td>
<td>18, 8</td>
<td>79, 8</td>
<td>88, 1</td>
<td>25, 1</td>
</tr>
<tr>
<td>Outlet T (°C), P (bar)</td>
<td><strong>108</strong>, 10</td>
<td>25, 10</td>
<td>25, 10</td>
<td>25, 10</td>
<td><strong>18</strong>, 8</td>
<td>25, 8</td>
<td>79, 8</td>
<td><strong>85</strong>, 1</td>
<td>64, 1</td>
<td></td>
</tr>
</tbody>
</table>
A numerical model needs to be verified with experimental data, whenever possible, to improve the validity of the model as a whole, as well as its results. For this reason, the ASPEN (numerical) model of the TCS system in this project (referred to as the "desired TCS system") is verified here by using experimental data from literature [25]. This is done by adapting the desired TCS system’s ASPEN model to reproduce the solar-driven TCS system from Erhard et al. [25] along with its components and operating conditions. This solar-driven TCS system employed 2.2 kg of SrCl₂ with 1.67 kg of NH₃ in a single reactor [25] (as in Figure 5). The Aspen model adapted to the system of Erhard et al. [25] is here referred to as the 'verification model', and is shown in Figure 6. In this model, the ice storage of Erhard et al. [25] was neglected for simplicity, as a reasonable assumption, as it does not directly affect the NH₃ sorption cycle. In the system of Erhard et al. [25], the same reactor undergoes desorption during the day (when sun shines) and absorption at night. In the verification model here, both these reactions are simultaneously represented by the two respective reactors in the desired TCS system model. Similarly, a common heat exchanger used by Erhard et al. [25] is separated-out into the cooler and heater in Figure 5, which already exist in the desired TCS system. The TCS system of Erhard et al. [25] (and hence the verification model here), excludes the compressor because it is designed for ambient temperatures around 40 °C at which NH₃ pressure reaches 16 bar (and is liquid), and by cooling this NH₃ the 3 bar reaction pressure is obtained. Furthermore, their system excludes a pump, as the liquid flow is operated under-gravity [25]. These aspects are maintained in the verification model here. The evaporative power of the system is reported to be 20 W [25], and the verification model simulation here also yielded the same evaporative power of 20 W. This result therefore verifies the validity of the ASPEN model of the desired TCS system in this work.

Figure 4. The real NH₃-SrCl₂ TCS system of the Aspen model with simultaneous absorption and desorption (HTF: Heat transfer fluid)

Figure 5. The real TCS system of Erhard et al. [25] used in the verification model construction
The ASPEN model yields the desired storage capacity of 0.5 kWh on each reactor, during absorption and desorption. The energy efficiency of the absorption and desorption half-cycles are respectively 67% and 61% (considering the total energy use in each half-cycle, for storing 0.5 kWh energy).

The sensitivity analysis on the HTF regarding the inlet temperatures of the external heater and cooler and the corresponding volumetric flow rates are summarized in Figure 7. As Figure 7 indicates, the volumetric flow rates of the HTF in the external heater and cooler to maintain the desired respective inlet temperatures of 88 °C and 25 °C, the HTF flow rates should be 5.3 l/min and 0.4 l/min respectively. These flow rates thus are reasonable for the chosen thermal bath’s capacity, and hence further verify the feasibility of the designed TCS system’s practical operation.

In-contrast to the most comparable TCS systems in literature, this TCS system design has the novelties of: being modelled in ASPEN (therefore with more flexibility in operating conditions analysis) for this specific layout and operating conditions; the use of an NH₃ buffer (allowing safer operation) unlike the system proposed by Nagamalleswara Rao et al. [27]; and allows simultaneous heat storage and release unlike in the TCS system at DTU [29].
As a next step in the project, the model will be used to investigate further the system’s behavior and the requirements of additional components (particularly compressors, heaters and coolers) for the entire operating temperature range of 80-40 °C. It will be used to assess the possible modifications to increase the TCS efficiency such as for example replacing the compressor by additional cooling steps, which would considerably reduce the electricity consumption. Overall, the bench-scale TCS system model in ASPEN will be thoroughly scrutinized and analyzed to find the optimal configuration to be built at KTH. The bench-scale TCS system, once constructed, is expected to yield practical implications in terms of its energy consumption, energy efficiency, energy losses, potential improvements, and experience for scaling it up. Such an ‘optimized’ practical system can be scaled-up to store waste heat from industries, data center servers, and like, that can then be used to complement district heating. The simultaneous operation at the bench-scale was sought here more for the concept demonstration and trouble-shooting of the complete absorption and desorption within the same cycle. Whereas, at an application, the additional reactor could serve as a back-up. Or else, this system can also be split, by constructing the absorption half-cycle at the heat consumer and the desorption half-cycle at the heat source, where each reactor and the ammonia storage are designed as removable and portable units that can be transported between the consumer and heat source.

4 Conclusions

This work successfully numerically modelled a TCS system in ASPEN using the system NH$_3$-SrCl$_2$, for the simultaneous heat storage (desorption) and release (absorption) at 82 °C and 79 °C (and 8 bar pressure) respectively with a heat storage capacity of 0.5 kWh. The system has an energy efficiency of 67% during absorption, and 61% during desorption. This TCS system model was verified against experimental results published for another rather similar TCS system using the same reaction pair, and a sensitivity analysis suggesting the optimum thermal bath flow rates to maintain the expected reaction temperatures. As the next steps, this system will be analyzed to find out if the use of the compressor can be replaced with more cooling steps for a more economical system, as well as for the entire operating temperature range 40-80 °C.

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References


