

Hybrid thermochemical process for storage and conversion into cold and electricity based on a low temperature thermal source

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Abstract. This paper presents a hybrid thermochemical process concept for the cogeneration of cold, electricity and thermal storage based on low temperature sources. Several innovative architectures of the process were defined at PROMES-CNRS and the 'simultaneous mode' architecture was chosen to be under study. It provides both cold and electricity productions in the discharging step of this storage system. A numerical model was developed at PROMES simulating the simultaneous mode of the hybrid cycle. Based on the results of the model, an experimental prototype was developed at the lab. The thermochemical reactor was tested and operated properly in the charging and discharging phase of the cycle, before its hybridization. The expander was set under the first experimental characterization using nitrogen before integrating it with the thermochemical reactor in the hybrid system to analyze the real performance of the cycle.

Keywords: hybrid thermochemical processes, cogeneration, cold production, electricity, thermal storage

1. Hybrid thermochemical processes

Energy policies include important issues such as the use of low-temperature heat sources (renewable, waste heat), the management of demand variability and energy storage sources, and a particular attention to the growing demand for electricity and cooling. In order to respond to this, thermochemical processes called 'hybrid' combining energy multigeneration and storage functions are being developed [1,2].

A thermochemical cycle is based on a reversible chemical reaction between a solid and a gas ($S' + \nu G \Leftrightarrow S + \Delta h_r$). Its operation is composed of two phases based on the two directions of these reversible transformations: the decomposition phase and the synthesis one. These two phases can be separated in time inducing the storage of the productions. In the decomposition phase, heat is supplied to the charged salt S to decompose it into a discharged salt S' and ammonia gas. In the synthesis phase, ammonia gas reacts with S' to reproduce the ammoniated salt releasing the reaction heat. Many applications are based on the endo or exothermic effects generated in these processes: cold production or heat source valorization in a wide range of temperatures depending on the chosen reactants (the salts) [3]. Hybrid cycles (figure 1) add an innovative functionality to these thermochemical cycles: it allows valorizing also the mass flow resulting from the gas/solid chemical reaction. For this purpose, an expansion device is inserted in the gas flow path, in one or both active phases, which then operates in a non-isobaric phase (contrary to the classical operation of sorption processes). Several architectures correspond to this hybrid process depending on the location of the expander in the cycle and on its activation (either during the charging phase, the discharging phase or

both). In this study, the proposed hybrid system operates in a simultaneous mode producing cold as well as mechanical power during the discharging phase (figure 2).

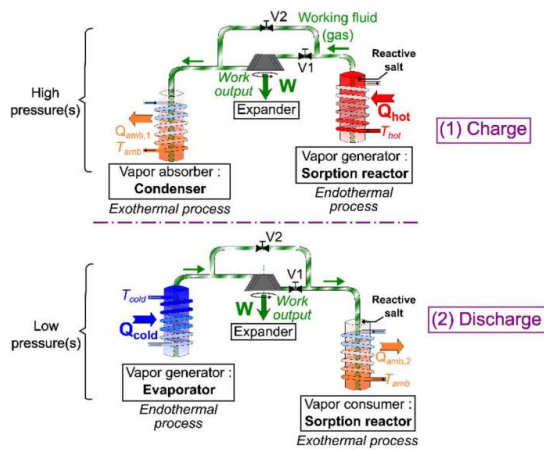


Figure 1- Hybrid thermochemical process: integration of an expander between the components of a thermochemical cycle.

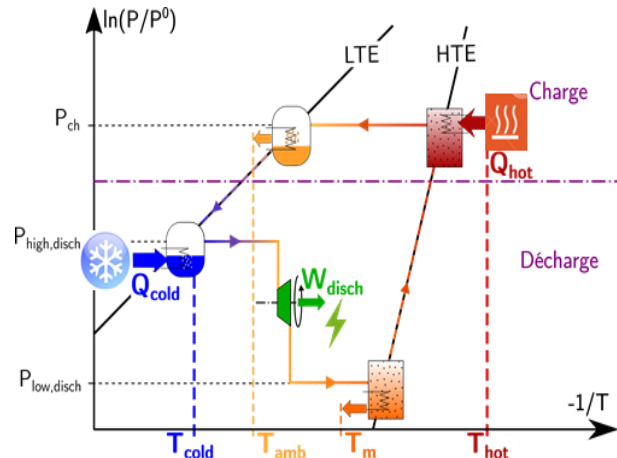


Figure 2- Thermodynamic path (Clausius-Clapeyron diagram) of the working fluid in the simultaneous mode of the thermochemical hybrid cycle.

2. Principle and coupling between hybrid cycle components

During the charging phase in the simultaneous mode of the hybrid cycle (from point 1 to 5 in figure 3), the reactor is heated from its equilibrium at the ambient temperature to T_h thanks to a heat input Q_h . This allows the decomposition reaction of the ammoniated salt ($S + \Delta h_r \rightarrow S' + v.G$). The condenser set at the ambient temperature in this phase will impose the saturation pressure of ammonia P_{cond} on the reactor allowing the desorption of ammonia gas from the reactor to undergo condensation at the ambient temperature. After the reaction is finished, the reactor is closed and cooled back to the ambient temperature, and ammonia liquid is stored inside liquid tanks during a storage phase.

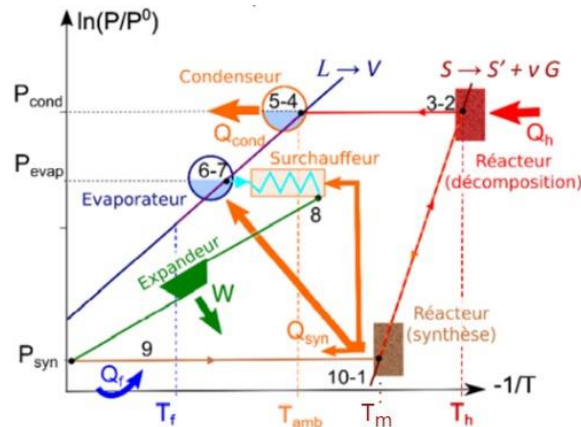


Figure 3- Description of the hybrid thermochemical process on Clausius Clapeyron diagram (from point 1 to 10): Thermal storage and simultaneous production of cold & electricity with internal heat recovery.

In the discharging phase (from point 6 to 10 in figure 3), the liquid ammonia evaporates at a cold temperature T_f to produce cooling effect. During its path towards the reactor, set at a medium temperature, ammonia vapor enters the expander at the vapor pressure P_{evap} producing mechanical energy and exits towards the reactor to perform the synthesis reaction at a lower pressure defined as the synthesis reaction pressure P_{syn} . While the synthesis reaction releases heat ($S' + v.G \rightarrow S + \Delta h_r$),

