OPERATION MODES AND PROCESS INTEGRATION OF A HIGH TEMPERATURE THERMOCHEMICAL HEAT STORAGE SYSTEM

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SUMMARY: This presentation will outline experimentally investigated operation characteristics of a 10kW thermochemical heat storage reactor based on calcium hydroxide. Important parameters such as charge and discharge temperatures as well as the corresponding vapor pressures will be determined. As an example, an integration concept for the thermochemical storage system in a concentrated solar power plant is derived taking operating conditions of the plant and the storage system into account. Through modeling of the overall system, valuable results are obtained regarding the incorporation of the heat fluxes and the reaction gas as well as their influence on the overall storage efficiency is studied.

Keywords: thermochemical energy storage, high temperature, calcium hydroxide, pilot plant, storage integration

INTRODUCTION

Efficient thermal energy storage systems for high temperatures at reasonable costs are essential for the economic success of concentrated solar power and can increase efficiency through the recovery of waste heat in industrial processes. Due to the good availability at low cost and its favorable temperature range, previous work at DLR focused on the reversible dissociation reaction of calcium hydroxide:

$$CaO_{(s)} + H_2O_{(g)} \leftrightarrow Ca(OH)_{2(s)} + \Delta H_{reaction} \quad (1)$$

Thereby, complete reversibility and cycle stability of the material has been demonstrated [1]. Additionally, due to its fast effective reaction kinetics, the high reaction enthalpy of 100 kJ/mol and the temperature range between 400°C and 600°C the system is a promising candidate for a high temperature thermal energy storage which could e.g. drive a conventional steam cycle during discharge.

In order to investigate the reaction system, a multifunctional test bench as well as an indirectly operated reactor for 25kg $Ca(OH)_2$ was developed and set into operation. With the experimental set up the feasibility to store heat chemically in a technically relevant scale (10kW) was demonstrated [2].

However, the heat recovery efficiency of the proposed reaction system depends mainly on the process and on the integration principle. It is obvious that the enthalpy of vaporization is an energetic effort and has to be taken into account if steam needs to be generated. Consequently the incorporation of the reaction gas in the application process is important to reach high overall cycle efficiencies. The partial use of low grade steam (100 °C) from the process, e. g. extracted from a steam turbine cycle, poses a possibility to drive the exothermic hydration reaction at 500°C. To evaluate the benefit of this thermal upgrade, a simulation of the overall process application is necessary.

OPERATION MODES OF A $Ca(OH)_2$ BASED PILOT REACTOR

Figure 1 shows the opened storage reactor. The storage material is placed in 20mm wide and 200mm deep channels each one separated by a thermo-shelve. Air, serving as the heat transfer fluid, enters the reactor at the two flange connections on the right hand side and flows inside the thermo-shelves taking up or delivering the heat of reaction.

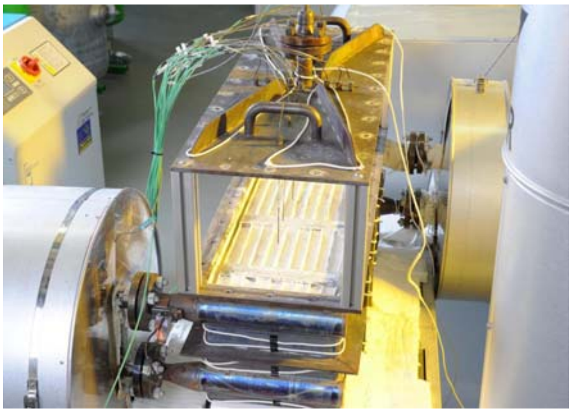

Figure 1. 10kW pilot reactor for $Ca(OH)_2$

The air then leaves the reactor at the left hand side. Through the pipe visible in the center of the cover the reaction gas enters and is distributed homogeneously in the reaction bed.

Multifunctional test bench

The storage reactor has been integrated in the multifunctional pilot plant shown in Figure 2. The plant is capable to investigate various thermo-chemical reactors with a thermal power of up to 10kW. Air can be supplied at an adjustable mass flow and temperatures up to 1000°C. An additional reaction gas unit supplies water vapor at respective pressures and temperatures.

Figure 2. Multifunctional pilot plant for thermo-chemical storage reactors

Operation modes

To identify a technical possible operation window of the $Ca(OH)_2$ storage system a series of experiments have been carried out with the reactor shown in Figure 1. Especially the influence of the reaction gas pressure on the material bulk and the storage temperatures was analyzed. As a result discharge temperatures of 490°C and 545°C were reached at respective steam partial pressures of 1 and 2 bar.

Figure 3 shows the trend of the temperatures in the material bed during hydration of CaO with a steam partial pressure of 1 bar. An equilibrium temperature plateau at 490°C can clearly be seen as well as the reaction front moving along the heat transfer fluid flow direction indicated by the consecutive drop of the temperatures [3].

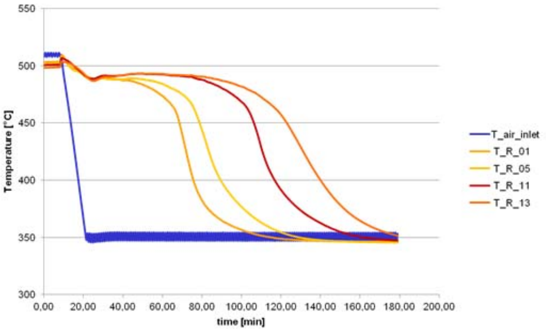

Figure 3. Temperature trend during hydration of CaO at 1 bar steam partial pressure

Charging of the storage reactor was realized at a vapor pressure of 100mbar and 400°C bed temperature.

PROCESS INTEGRATION OF A $Ca(OH)_2$ STORAGE SYSTEM

Model of the $Ca(OH)_2$ storage system

Based on the experimentally investigated behavior of a large bulk of the storage material [3] and the determined material properties [1] a simplified model of the storage system was developed. Simulation results of the model showed precise agreement with the experiments for steady state operation conditions. The model was implemented in a commercially available power plant simulation tool.

System modeling

A reference power plant with a nominal power of 30 $MW_{electrical}$ was modeled and the storage system was integrated (Figure 4). For the charging mode the power of the heat source (e. g. a solar field) was increased stepwise while the power block was still running at nominal electrical power. Available excess heat was used to charge the storage reactor. As a result the amount of charged material, within a period of eight hours charging time was determined for various plant configurations.

For the discharge mode the achieved hours of nominal electrical power for different points of the incorporation of the reaction gas were determined. Thereby, possible operation strategies were investigated in order to increase the overall cycle efficiency.

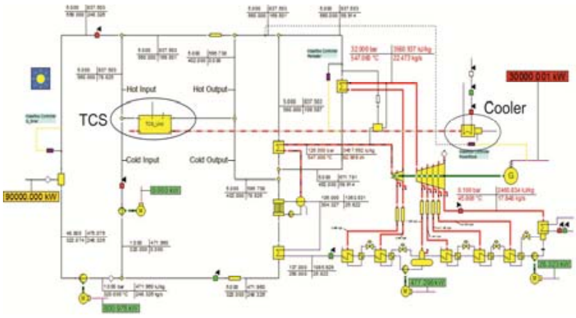

Figure 4. Model of a power plant with an integrated thermochemical storage system

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