Experimental proof of concept of a pilot-scale thermochemical storage unit

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1. Introduction

An efficient heat storage system, which allows disposal of the energy independently of the weather conditions, is a key factor on the development of Concentrated Solar Power (CSP). In this respect thermochemical heat storage could play an important role. Despite being still at early development stage, the number of recent studies dealing with thermochemical systems for high temperature storage shows that the interest on this topic is largely increasing. Among the reactive materials studied, certain multi-valent metal oxides seem to be a promising option, especially for air-operated CSP plants.

Experimental studies dealing with such materials so far refer to lab-scale reactors [1, 2, 3]. In such systems although the reactions are clearly detected by product gas analysis, their heat effects cannot always be detected equally clearly. The main reasons are the relatively low amount of redox material used and the high heat losses involved. A pilot-scale set up can decrease such losses through the outer wall by increasing the volume/surface ratio.

The first pilot-scale redox-thermochemical storage unit, presented in this paper, was built and installed at a solar facility, the Solar Tower Jülich (STJ), in Germany. The present study relates to its construction and implementation and reports the first experimental results. The heat release could evidently be detected and the concept could be proven.

2. The system

In the present system, the reactive material (cobalt oxide in its oxidized state Co_3O_4) is shaped in structured monoliths through which air can flow [1, 4]. The monoliths are honeycomb bricks made either by directly extruding a cobalt oxide/alumina composite or by coating the cobalt oxide on a ceramic honeycomb support, like cordierite. This new concept exhibiting high surface area and good heat transfer properties was previously tested at lab-scale conditions by APTL [5]. The extruded option contains a higher amount of reactive material per unit volume i.e. a higher energy density and thus was the preferred choice. Despite the very good results obtained for small cylindrical bricks, attempts for scaled-up production were not successful. Honeycombs of reactive material of cross-section 100x100-mm could be successfully extruded by Liqtech, but during calcination their structure collapsed. Several calcination protocols were followed, but it was not possible to obtain structurally stable honeycombs with cross-section larger than 30x30mm. Further efforts on this matter are in progress, but in parallel the second option was set forth: the cobalt oxide was coated on honeycomb-shaped inert supports. In total, 88 kg of cobalt oxide were coated on 128 cordierite honeycombs of 150x150 mm cross-section. The reactive material represented ~ 32% of total mass.

The prototype reactor (Fig. 1a) comprises two identical chambers, whose shape is optimized through numerical calculations [6]. During charging, the air flow, obtained as a side-stream of the STJ and driven by a blower, is measured through a flowmeter and over-heated up to 1100°C by a gas burner. The air flow splits into the two reactor chambers, where the air exchanges heat with the solid material. After exiting the two chambers, the two air flows merge and pass through a filter that serves as fail-safe in case of particles entrainment. The “clean” hot flow is mixed with cold air and released to the environment. Temperature and pressure sensors are placed in multiple locations along and across the system.

3. Experiments

A complete charge-discharge cycle is shown in Fig. 1b: the temperatures of the top (red and blue curve), middle (green and orange) and bottom (dark and bright purple) are shown for the left and right chambers. During charge (blue rectangle in Fig. 1b) the inlet air temperature is about 1100°C. The top temperature increases fast. At 890°C, a small step is recorded. This step becomes much more pronounced in the middle of the reactor, where a plateau appears in the middle of the charge (dark blue rectangle in Fig. 1b). At the beginning of the charge, the heat transferred from the air to the solid leads to an increase of the solid temperature (sensible storage). When approaching the reduction temperature of Co_3O_4, the reaction starts and the heat is totally absorbed by the endothermic reaction (chemical storage), so the solid temperature remains constant. When the chemical reaction reaches completion, the energy is again stored in its sensible form, leading to heating up of the solid material until steady state is reached. During discharge (red rectangles in fig. 1b) air enters at 700°C. The heat is firstly released in sensible form, thereby cooling down the solid until the oxidation temperature of CoO. At this point, the air flow is heated up by the exothermic reaction and the solid maintains a constant temperature. After reaction completion, a second sensible cooling leads the solid temperature to reach the inlet air temperature.

In sensible-only heat storage, temperature increase would be constant. The presence of the plateau is attributed to a clear chemical storage effect. The length of the plateau is proportional to the chemical energy stored inside the system.

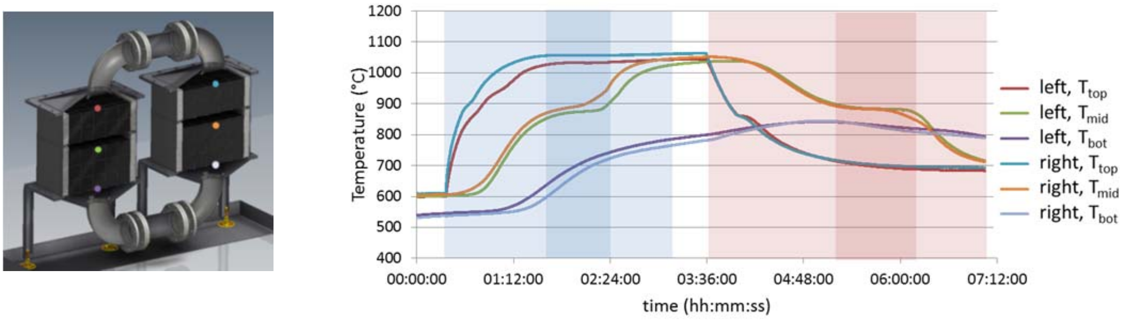

Fig. 1: a) prototype reactor; b) experimental results of one thermochemical charge and discharge cycle

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