# Design of a thermochemical storage system for air-operated solar tower power plants


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## 1. Introduction

The efficient storage of solar energy is a quite challenging issue. At present, several commercial storage systems are available storing the heat in its sensible form, using liquid or solid storage media. The latter is used for instance in air-operated solar tower power plants, like the Solar Tower in Jülich (STJ) [1]. During "charging" (on-sun operation) the hot air coming from the receiver is transferred to a ceramic storage assembly, with honeycomb-like structures, to provide a large heat exchange surface area between air and the solid storage medium [2]. During "discharging" (off-sun) operation the air flow is reversed: "cold" air is introduced in the storage medium to be heated by that before sent to the power block.

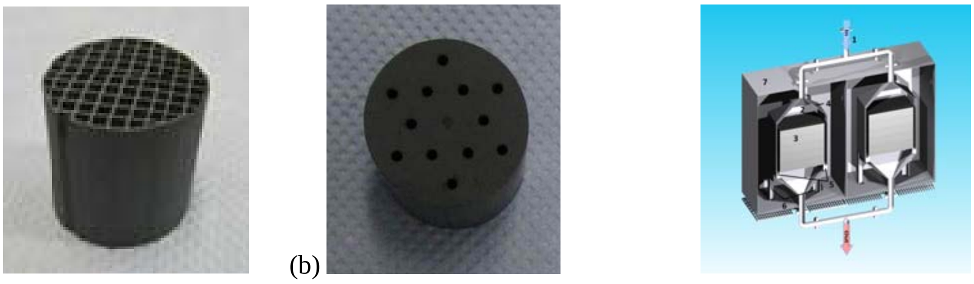
The energy stored in this system, can be strongly increased by replacing the storage material with a material having a similar structure, but able to also participate in a reversible chemical reaction in the temperature range of interest. In this way, not only the sensible but also the chemical heat (of reaction) will be stored. This could offer higher energy density and possibility of storing the heat at higher temperature for longer time periods. To explore this concept, monolithic bodies made of a reactive material (cobalt oxide) were prepared and the proof-of-concept feasibility was verified [3]. The results are used for building a thermochemical storage system prototype, implemented for the first time in an existing solar facility (STJ).

## 2. Storage shape

The reactive material can be structured in different ways to enhance heat transfer; two such particular examples (i.e. a honeycomb and a perforated block) were manufactured. Indicative photographs of such structured bodies are provided in Figs. 1 (a) and (b). Such multiple shaped blocks can be assembled, to form the core of the storage prototype block (black part in Fig. 1 (c)). The optimal reactor shape is investigated using a simplified model for the two material structures above and compared to a reference case - a packed bed of the same powder. The simplified model considers pressure drop inside the porous structure storage block and convection + radiation heat losses from the external walls. These losses are weighted and summed up allowing the definition of an optimum shape. Every reactor has a square base of side L and a height of H. The aspect ratio $f$ is defined as: $f = H/L$. The losses of the perforated block are smaller than those for the other two formulations, due to the lower volume (and therefore smaller surface area) required. The minimal losses are ca. 26% of the chemical stored power, slightly lower than those for the honeycomb case. However, the chemical conversion, not considered in this simplified model study, obtained with this kind of reactor is expected to be lower. Therefore, a larger volume will be needed to store the same energy and eventually this particular design is likely to converge with the honeycomb formulation.

## 3. Load tests

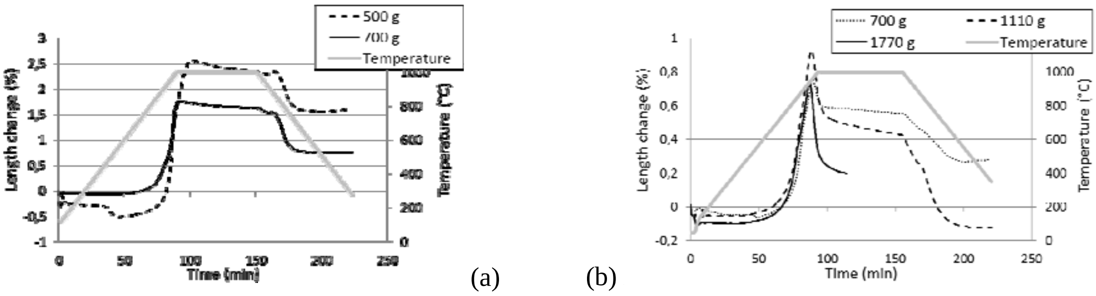
In order to test the mechanical strength of the system, the samples were thermally cycled under mechanical loading, applying variable loads. The experimental set-up allows to apply a load on the structured sample while it is subjected to thermal cycling. At the same time, potential dimensional changes are continuously recorded. The optimal shape, in terms of $f$, defines the load variation range in the experiments. Three loads were applied, corresponding to the pressure applied on the lower surface of the reactor (i.e. worst case scenario), due to the material weight. The results for a honeycomb and for a perforated block made of 90/10 wo% cobalt oxide/aluminina composites are shown in Figs. 2 (a) and (b) respectively. First the sample contracts (negative length change) due to applied pressure. Afterwards, a very slight expansion can be observed, probably due to the thermal effect.



(a) (b) (c)

Fig. 1: Reactive material structured as (a) honeycomb and (b) perforated block. (c) Schematic of the prototype reactor which will be installed in the STJ

Once the reaction temperature is reached, the sample expands abruptly. The maximum expansion at this stage was about 2.5% for the honeycomb and less than 1% for the perforated block. Afterwards, the sample contracts slowly, due to the load. Finally, upon occurrence of oxidation (cooling down step) an abrupt contraction is observed. An important result is that the load decreases the over-all sample expansion, for both the honeycomb and the perforated block. Moreover, the perforated block shows lower expansion than the honeycomb. A second important result shows the increase on the mechanical strength when adding 10% aluminium oxide to the composition of the sample. The honeycomb entirely made of cobalt oxide broke during the first cycle (load = 500g), while the composite sample could sustain both loads.




(a) (b)

Fig. 2: Length change during a thermal cycle, applying different loads for (a) honeycomb and (b) perforated block made of 90/10 wt% cobalt oxide/alumina composite

## 4. Design

Following the promising results obtained, a prototype reactor will be installed in STJ. The reactor's pre-design is shown in Fig. 1(c). The storage module is separated into two, identical reactor chambers, which can work separately. The reactive material is in the central parts of the chambers. The gas, entering from the top of the reactor, flows through a conical inlet, which guarantees a more uniform air distribution before it comes in contact with the reactive material. The structured reactive assembly is supported on a grid holding structure (3). The honeycombs are fixed horizontally with a small layer of insulation material, in the gap between the inner housing (4) and the reactive material. This will also absorb possible dimension variation during the cycling. The grid is placed on a square metal plate (5), connected to the inner housing hull. The inner housing has four feet (6), assembled at the 4 edges. Those are connected to the ground and fixed. The reactor chambers are housed with the outer hull (7), which is filled with high temperature insulation material. A CFD model, developed in a parallel study will be used to refine the design and define operating conditions.

## References

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