A cost-effective open volumetric air receiver design based on free floating stackable absorber modules

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1. Introduction

The CAPTure (Competitive SolAr Power Towers) H2020 project lasted from May 2015 to July 2020 and was focused on an innovative central receiver CSP plant configuration, investigating the application of an open volumetric air receiver (OVAR) for heat supply at highest temperature in order to power a combined cycle (CC) – topping Brayton, plus bottoming steam Rankine cycle – for efficient and competitive renewable power generation [1]. Due to an innovative air-air heat exchange system, it is possible to externally heat the topping Brayton cycle using an open volumetric air receiver without the need of a pressurized air receiver. This approach is highly advantageous for three reasons: (i) no fragile quartz window is needed, (ii) higher efficiencies and flux densities compared to tubular or opaque heat exchanger type receivers can be achieved, and (iii), a very cost effective thermal energy storage (TES) system can be installed upstream the gas turbine [1], allowing dispatchable operation of the power cycle, a must for CSP.

2. The novel OVAR design based on free floating stackable absorber modules

The CAPTure OVAR technology is a simplified version of that developed in previous OVAR research projects [2, 3]. The key modification is that no return-air stream is implemented due to a different power cycle architecture. The receiver design is modular, based on individual absorber modules (cups), using open-celled ceramic foam of SSiC (pressureless sintered Silicon Carbide) as solar absorber material (Fig. 1), in contrast to honeycomb-type ceramic solar absorbers used previously [2, 3]. Each cup contains the solar absorber matrix. In order to adjust the mass flow locally (different air outlet geometry for each cup) according to the given solar flux map, a modular design is required. Zones with higher incident flux density need higher air flows, thus lower flow resistance (e.g. larger outlet orifice diameter or variable foam thickness). The aim is to achieve the same air outlet temperature for all absorber modules. The novel approach of the CAPTure receiver is that the design is considerably simplified compared to previous research projects [2], where a very complex metallic double membrane structure was used to serve as absorber module mounting structure. Ideally, the whole receiver and absorber structure should be made of ceramic material in order to reduce complexity of thermal insulation and costs. The CAPTure design applies the novel concept of "*free floating*" absorber modules. The idea is that the ceramic absorber modules themselves, in stacked configuration, form the receiver structure only exposed to compression loading in the vertical walls. Ceramic materials are most resistant to compression loading, while bending stress and ductile stress should be avoided. At the same time, the compression loading must be kept within limits, such that thermal expansion does not introduce additional stress to the existing compression stress due to the weight of the absorbers. Therefore, thermal expansion must be taken into account, and all absorber modules of the receiver must be able to expand freely according to their specific temperature distribution and heat load. The design concept is based on stackable, free-floating ceramic modules that are arranged in vertical columns. Each column is able to expand upwards according to its specific temperature distribution (Fig. 1 (a, c)). Additionally, the free gap between each column is the space needed for free thermal expansion in horizontal direction. The vertical movement and the correct horizontal position of each column is guaranteed by a set of guiding elements, which are in this specific implementation proposal, ceramic tubes (Fig. 1 (a)). This configuration with ceramic guiding tubes allows also thermal instrumentation of each cup. This novel design has been implemented at a 300kW$_{th}$ research prototype at CIEMAT-PSA and has been successfully tested at representative flux conditions without failure. In addition, the receiver design has been tested at cup-level at the Synlight facility at DLR (thanks to SFERA-III framework), further validating the concept at temperatures up to 900ºC. The foam, cup and receiver design has been optimized using simplified 1-D as well as detailed CFD models.

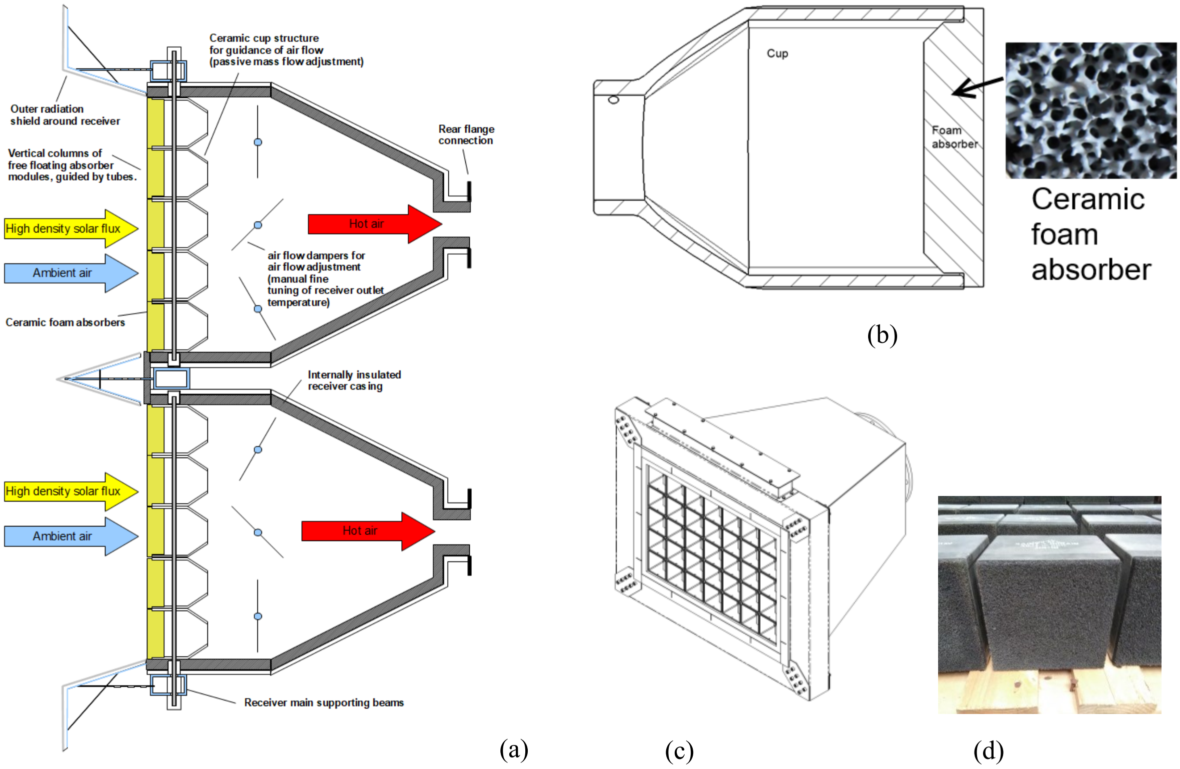

Fig. 1: Open Volumetric Air Receiver (OVAR) concept (a); Stackable absorber module (b); CAPTure 300 kWth prototype without foam absorbers (c); CAPTure absorber modules before receiver mounting (d).

3. Conclusions and outlook

This work presents the CAPTure OVAR design that is based on ceramic stackable "*free floating*" absorber modules that form the receiver structure and avoid a complex metallic double membrane structure. The new approach considerable simplifies the design and reduces receiver costs. Furthermore, the upscaling is simple. Nevertheless, the maximum stackable column height must be considered, which is defined by mounting limitations and material compression strength. Therefore, also the up-scaled receiver design will be based on a modular approach, where a reasonable aperture area of one module would be about 18 m^2 (6 m x 3 m), falling approximately into the 5 MW$_{th}$ power class. The final receiver would then be composed of several identical 5 MW units. Figure 1 (a) displays the concept having two receiver modules placed on top of each other. The full paper will give more details regarding the receiver design as well as its experimental validation at different scales (300 kW$_{th}$ onsun testing at CIEMAT-PSA, CAPTure H2020 project; as well as 15 kW$_{th}$ testing at the Synlight facility at DLR, thanks to SFERA-III framework).

References

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