Innovative High-Temperature Air-Based Integrated CST for Flexible Renewable Heat

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High temperature industrial processes represent a critical challenge for decarbonization. Concentrating solar technologies have the potential to attain the required high temperature (>600°C). However, innovation is needed to ensure a **scalable solution able not simply to generate hot air but to make it flexibly and cost-effectively available to the end user**. Traditional air based solar thermal receivers such as open volumetric units have stationary absorbers which impose limitations on the receivable flux due to the heat transfer capabilities of the air flow. The development of rotary-type receivers opens the potential for higher transient operating temperatures. The development of ODQA's, (https://www.odqa.com/), a spin-off of the University of Oxford, rotary solar thermal receivers began in 2019, incorporating advanced thermal management strategies adopted from gas turbine technologies to provide **highly effective heat transfer at high temperature** (>1000°C). ODQA's receiver is a **pressurized rotary tubular heat absorber encased in an insulation casing with a front aperture**. Shadow plates surrounding the aperture and gathering otherwise spilled energy have also been developed ensuring an efficient pre-heating and losses minimization. Since 2019, different prototypes have been developed and have provided a solid validation of the technology: 10 kW unit validated in an in-house solar simulator and on-sun testing at PROTEAS (Figure 1), a 100 kW unit validated at DLR's SynLight solar simulator (Figure 2). The main performance attained by these units is reported in SolarPaces publications[1]. Solar receivers' development alone is not sufficient. The integration of thermal energy storage (TES) is the key competitive advantage for CST units to ensure operational **flexibility**[2]. Packed-bed TESs store sensible thermal energy by heating and cooling solid particles and providing different advantages[3]. Technology's main limitations are **pressure drop, thermal losses, and thermal stratification degradatio**n. To address these challenges, over the last 6 years KTH has developed and validated **innovative high-temperature radial flow packed bed TES solutions that could ensure a more rapid and smoother transition toward full commercialization for high temperature CST units**. Latest developments include layered arrangement. CADs and photographs of the TES solutions (~50 kWh) are shown in Figure 3 and Figure 4. The developed TES units have been fully validated via two extensive experimental campaign up to TRL 6: at KTH high temperature TES rig (Figure 5), and within ODQA's facility in integration with ODQA's high temperature 10 kW rotating air receiver (Figure 6 and Figure 7). The main advantages attained by this TES configuration as fully reported in peer-reviewed journals[4,5], are 1) a **reduction of the pressure drop higher than 50% and higher than 80% when coaxial layers are included with respect to traditional axial flow packed bed TES**, which leads to a corresponding reduction of the parasitic consumption Figure 8; 2) **cost and environmental impact reduction of about 60% with respect to commercial TES** solution thanks to cheap and natural storing material (waste upcycling); 3) **lowered thermo-mechanical stresses on the TES tank**, due to a more uniform temperature at the TES wall during operation, **limiting structural challenges for the TES upscaling**; 4) ensured **operation at high temperature**.

Upscaling and integrated technological derisking are ongoing within an integrated TRL8 campaign carried out at PSA including a 50 kW rotating ODQA's receiver, purposely design pipework (essential to ensure cost-effectiveness), a packed bed TES unit and rotating kiln for ceramic drying (as a key representative industrial user) (Figure 9). In parallel further technological improvements are ongoing at KTH high temperature rig considering a structured radial flow TES with waste ceramic based bricks and embedded electric heaters the HE project FLUWS as sketched in Figure 10 (https://cordis.europa.eu/project/id/101147257 GA No 101147257).

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[1] Kwan, P., et al. 2024, "Upscaling and Testing of Air-Based Rotary Solar Thermal Receivers for Concentrated Solar Power Applications," SolarPACES 2024, International Conference on Concentrating Solar Power and Chemical Energy Systems.

[2] Liu M, et al. Review on concentrating solar power plants and new developments in high temperature thermal energy storage technologies. Renew Sustain Energy Rev 2016;53:1411–32.

[3] G. Zanganeh, et al., Packed-bed thermal storage for concentrated solar power - Pilot-scale demonstration and industrial-scale design, Sol. Energy, 2012

[4] Trevisan S, Wang W, Guedez R, Laumert B. Experimental Evaluation of an Innovative Radial-Flow High- Temperature Packed Bed Thermal Energy Storage. Appl Energy 2022;311. https://doi.org/10.1016/j.apenergy.2022.118672.

[5] Trevisan S, Wang W, Guedez R, Laumert B. Experimental evaluation of a high-temperature radial-flow packed bed thermal energy storage under dynamic mass flow rate. J Energy Storage 2022;54. https://doi.org/10.1016/j.est.2022.105236.

Figures

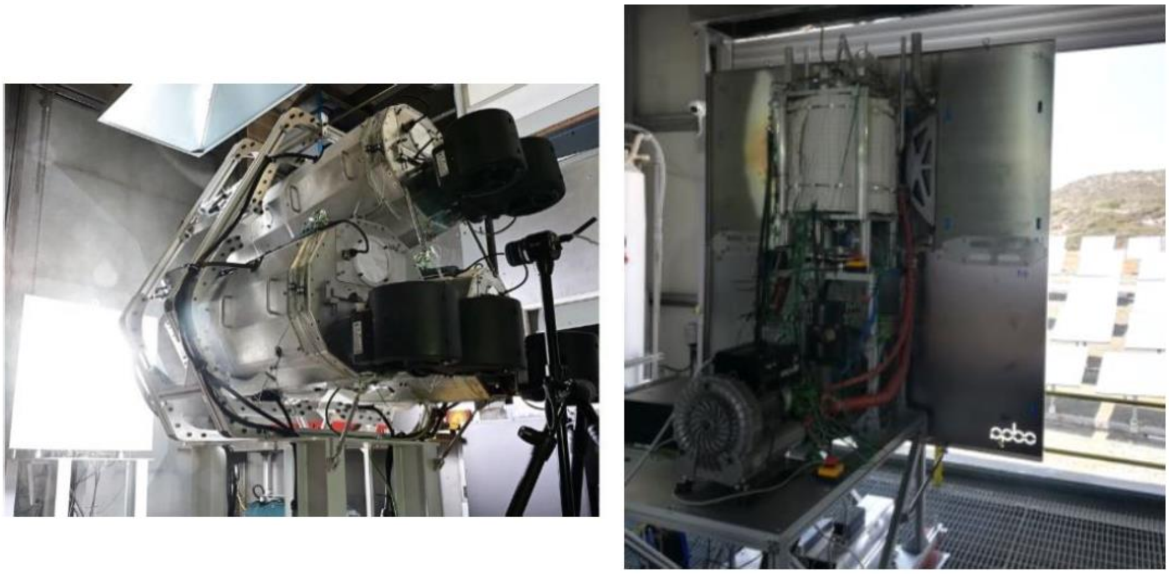

Figure 1: 10 kW rotating receiver prototypes under testing at ODQA's solar flux simulator (left) and at PROTEAS (right)

Figure 2: 100 kW ODQA's receiver prototype testing at DLR's SynLight solar simulator.

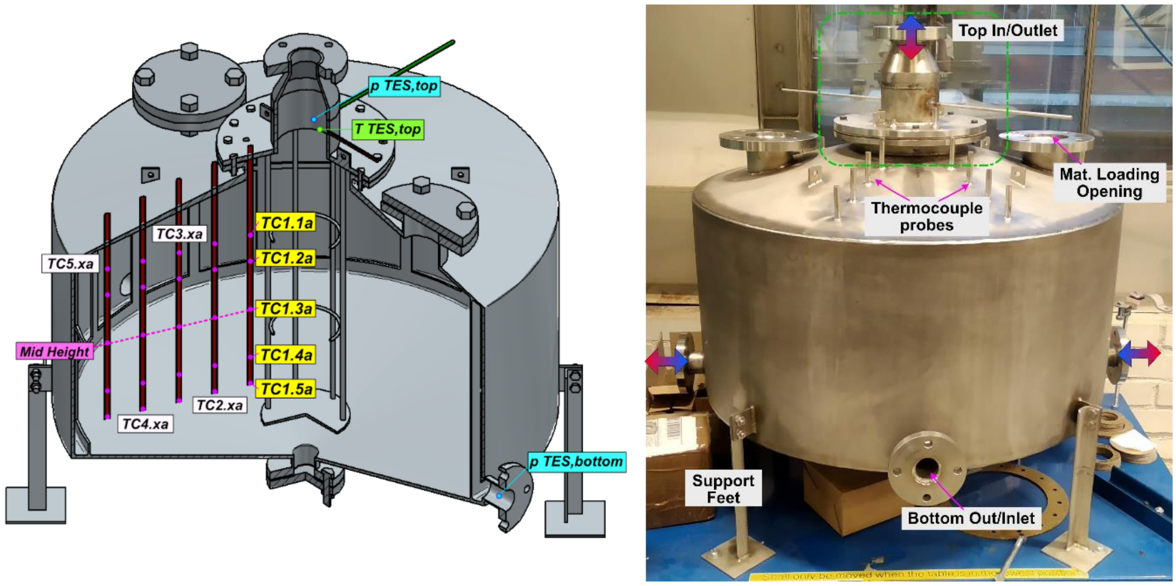

Figure 3: Innovative high-temperature radial flow packed bed TES CAD (left) and 50 kWh validated prototype (right).

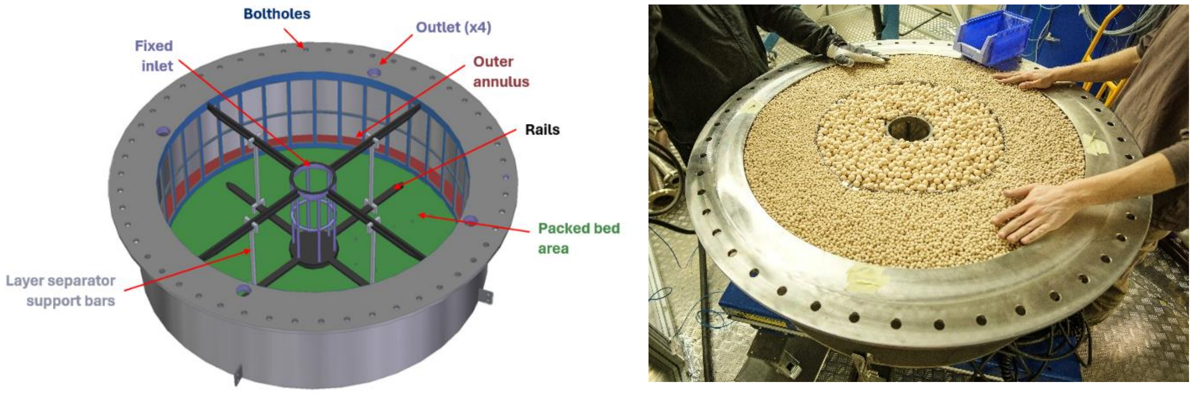

Figure 4: CAD of the advanced layered radial packed bed TES (left) and its validated prototype (right)

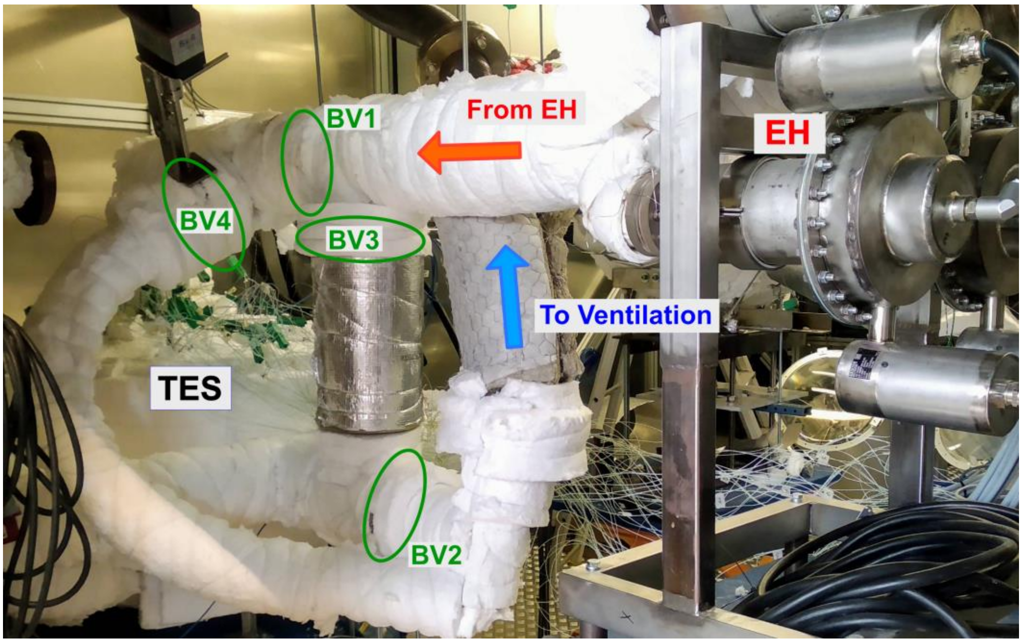

Figure 5: KTH high temperature TES rig exploited for TES validation up to TRL5 and high flux solar concentrator

Figure 6: TES assembly at ODQA's facility

Figure 7: TES under validation at ODQA's facility

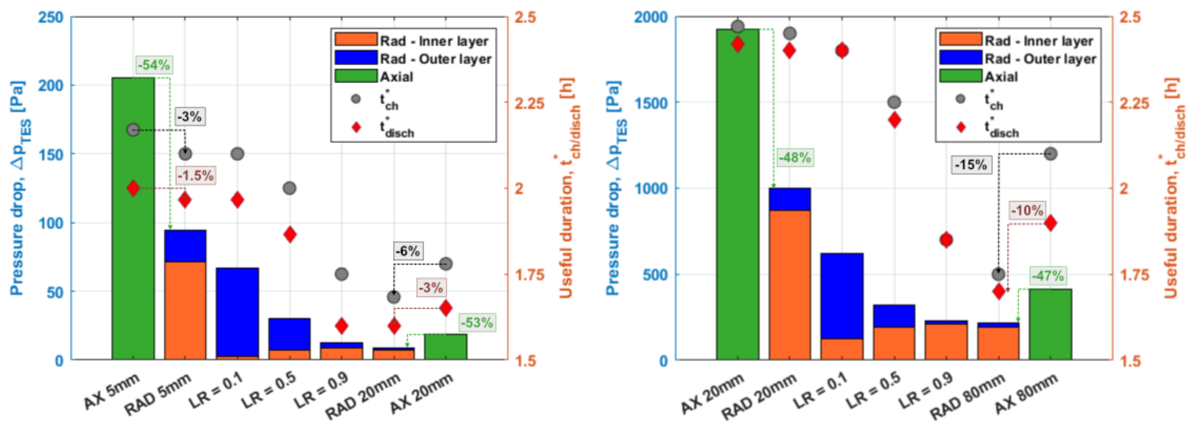

Figure 8: Pressure drop reduction attainable by radial flow TES (RAD) in comparison with similar axial flow packed bed TES (AX) and further performance improvement attainable by the layered configurations (LR). Results reported for a lab scale TES unit of 50 kWh (left) and for an industrial scale TES unit of 10 MWh (right).

Figure 9: Integrated TRL8 CST system for cost-effective and flexible high temperature industrial heat as demonstrated at PSA.

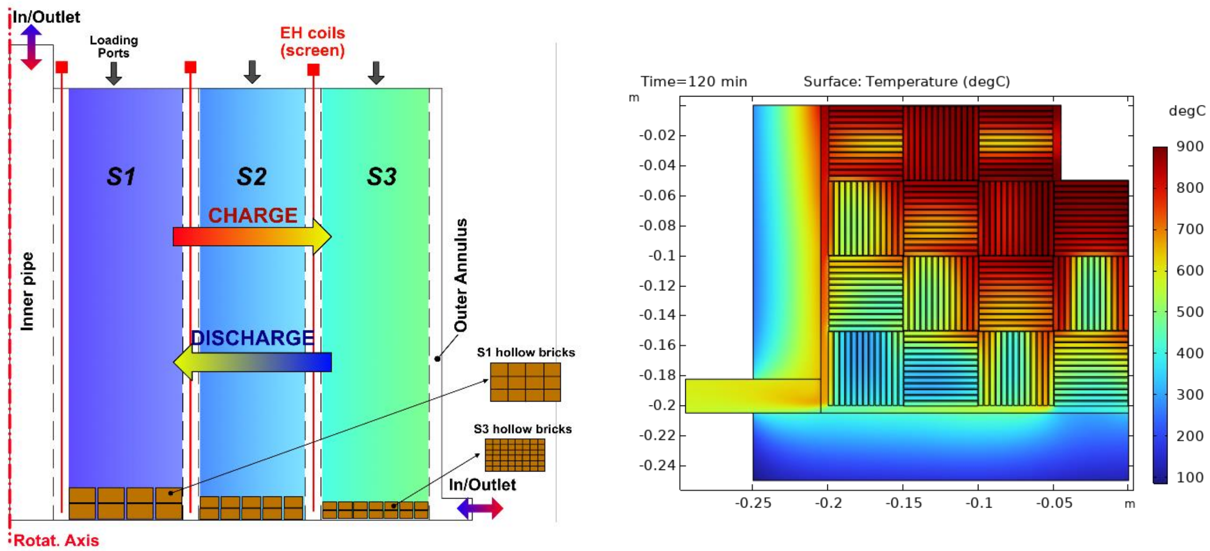

Figure 10: High temperature structured radial flow TES as further developed within the FLUWS HE project.

Role of the Applicants

Silvia Trevisan, PhD, Konstantinos Apostolopoulos-Kalkavouras, and Rafael Guedez, PhD - from the Energy Dept. at KTH, Royal Institute of Technology, Sweden – Pok-Wang Kwan and MyeongGeun Choi from ODQA Renewable Energy Technologies and Peter Ireland from the University of Oxford are the applicants of this proposal. Pok-Wang Kwan and Peter Ireland led the work in the design of the high temperature rotating receiver and its technological advancement. Silvia Trevisan carried out the main work in relation to the ideation of TES technology, design optimization, experimental validation and critical assessment. Konstantinos Apostolopoulos-Kalkavouras supported the latest TES design optimization and further experimental validation. Rafael Guedez supported the work particularly during the initial technology ideation and its critical assessment toward further performance optimization and upscaling. Both Silvia and Rafael currently work as ad hoc technical and strategy advisors for ODQA. MyeongGeun Choi, together with the main technological support of Peter Ireland, is driving the TES development and upscaling from ODQA.

Links to main supporting documentation

The work and technology innovation described have been widely described in peer-reviewed journals and conference publications:

1. Trevisan S, Wang W, Guedez R, Laumert B. Experimental Evaluation of an Innovative Radial-Flow High- Temperature Packed Bed Thermal Energy Storage. Appl Energy 2022;311. https://doi.org/10.1016/j.apenergy.2022.118672.

2. Trevisan S, Wang W, Guedez R, Laumert B. Experimental evaluation of a high-temperature radial-flow packed bed thermal energy storage under dynamic mass flow rate. J Energy Storage 2022;54. https://doi.org/10.1016/j.est.2022.105236.

3. Kwan, P., Pearce, R., Ireland, P. T., Ngai, C. C., Mallon, O., Wood, E., Loasby, M., and Karaca, G., 2023, "Development of Rotary Solar Receiver and Solar Simulator Facility for Concentrated Solar Power Applications," SolarPACES 2022, 28th International Conference on Concentrating Solar Power and Chemical Energy Systems, pp. 1–8.

4. Trevisan, S., and Guedez, R., 2024, "Design Optimization of an Innovative Layered Radial-Flow High-Temperature Packed Bed Thermal Energy Storage," J. Energy Storage, 83(January), p. 110767. https://doi.org/10.1016/j.est.2024.110767

5. Kwan, P., Loasby, M., Wambarsie, A., Ngai, C. C., Ireland, P. T., Baddeley, J., Marceta, K., Mallon, O., Kaya, A., Mountain, D., Battams, S., Cooper, A., Choi, M., Wilson, G., Ashley-Morgan, K., and Karaca, G., 2024, "Upscaling and Testing of Air-Based Rotary Solar Thermal Receivers for Concentrated Solar Power Applications," *SolarPACES 2024, International Conference on Concentrating Solar Power and Chemical Energy Systems*.

A wider analysis including several aspects from material to system integration has been presented in an approved PhD Thesis.

6. Trevisan S. Renewable Heat on Demand High-temperature thermal energy storage: a comprehensive study from material investigation to system analysis via innovative component design. KTH Royal Institute of Technology, 2022. http://kth.diva-portal.org/smash/get/diva2:1643005/FULLTEXT01.pdf