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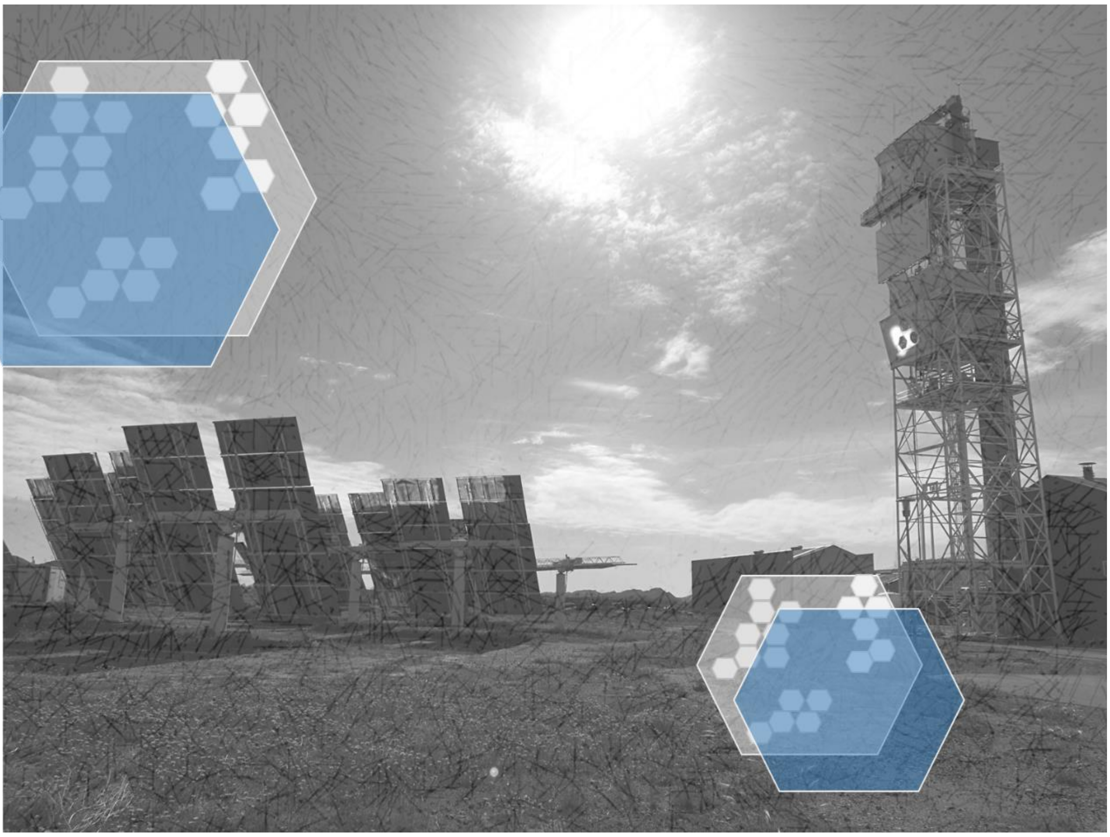
GA: 826379 H2020-JTI-FCH-2018-1



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1st PR-Publishable Summary

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PUBLISHABLE SUMMARY

1.1. Objectives

The principal objective of HYDROSOL-beyond project (GA: 826379, H2020-JTI-FCH-2018-1) is to capitalize an existing operational infrastructure of concentrated solar thermal power for the production of Hydrogen from the dissociation of water via the redox-pair-based thermochemical cycles, a process known as HYDROSOL. The activities of the project are organized in 9 work packages, including the research and experimental activities (WP2 – WP7), the feasibility assessment of the technology (WP8), the coordination and management of the project (WP1), as well as the efficient exploitation of the HYDROSOL-beyond outcomes (WP9). The main objectives of the project, for the 1st reporting period, are the following:

WP2	- detailed design of the complete advanced demonstration plant - definition and specifications of all additional plant components and interfaces - development of system control schemes - process control and automation
WP3	- concepts that minimize the consumption of flushing gas - concepts that allow heat recovery rates of high temperature heat in excess of 60 % - suitable and robust ceramic structures for heat recovery
WP4	- lab-scale development of next generation redox structures with enhanced activity - long-term stability, cyclability and performance validation studies at lab-scale and representative conditions - activity over at least 1000 cycles of operation
WP5	- address challenges of already existing structured reactors: alternative reactor/reactor key-components designs and evaluation - improve reactor performance
WP6	- adapt the solar tower platform to the new hydrogen plant operation requirements
WP7	- validate the performance of key plant materials and components for a minimum period of 6 months
WP8	- assessment of the technical and economic viability - benchmarking with other relevant processes
WP9	- project website - dissemination of the project's results - plan for the exploitation of the project's results

Figure 1. Overview of the thermochemical solar plant in Almeria, Spain.

1.2. Explanation of the work carried during the current reporting period

WP1 deals with the management activities of the HYDROSOL-beyond project. During the first reporting period (M1 - M24), the project management activities, were carried out as planned without the occurrence of any significant issue. The Consortium Agreement (CA) has been created and signed by all project partners. Its maintenance is APTL/CERTH's responsibility and all activities performed within the framework of the project during the reported project period are in line with the CA.

WP2 contains an improved process lay-out including a new strategy of operation with an automation concept. The new features of the plant, i.e. an improved heat recovery rate and two different concepts for Nitrogen regeneration have been presented. Subsequently the updated flow diagram and P&ID diagram have been obtained, incorporating the novel components along with the major unit operations which are already implemented in the plant on the Plataforma Solar de Almería. The control strategy has been based on the simultaneous operation of the solar reactors in order to have continuous hydrogen production. Nonetheless via this method, the total energy demands of the system remain constant throughout the operation of the plant.

The main tasks within WP3 are the minimization of N_2 and the development of a novel heat exchanger operating at extremely high temperature, above 1000^{o}C. Regarding the first objective, two different concepts have been examined: the purification of the nitrogen either via a thermochemical route (employing redox materials capable of oxygen exchange, similar to the WS process) or by pressure swing adsorption. Preliminary studies have proved the feasibility of both options, though the latter has been selected to be implemented in the solar plant, because of the higher readiness level and the maturity of PSA technology. As far as the heat exchanger is concerned, an elaborative investigation has been conducted in order to identify the most promising materials, configuration and specifications of the apparatus.

Computational fluid dynamic models have been developed to conclude to the final design of the heat exchanger (Figure 2). The high-temperature heat exchanger has a plate-fin configuration, consisting externally of metal plates, while on the inside consists of cellular ceramic lattice inserts (Figure 3).

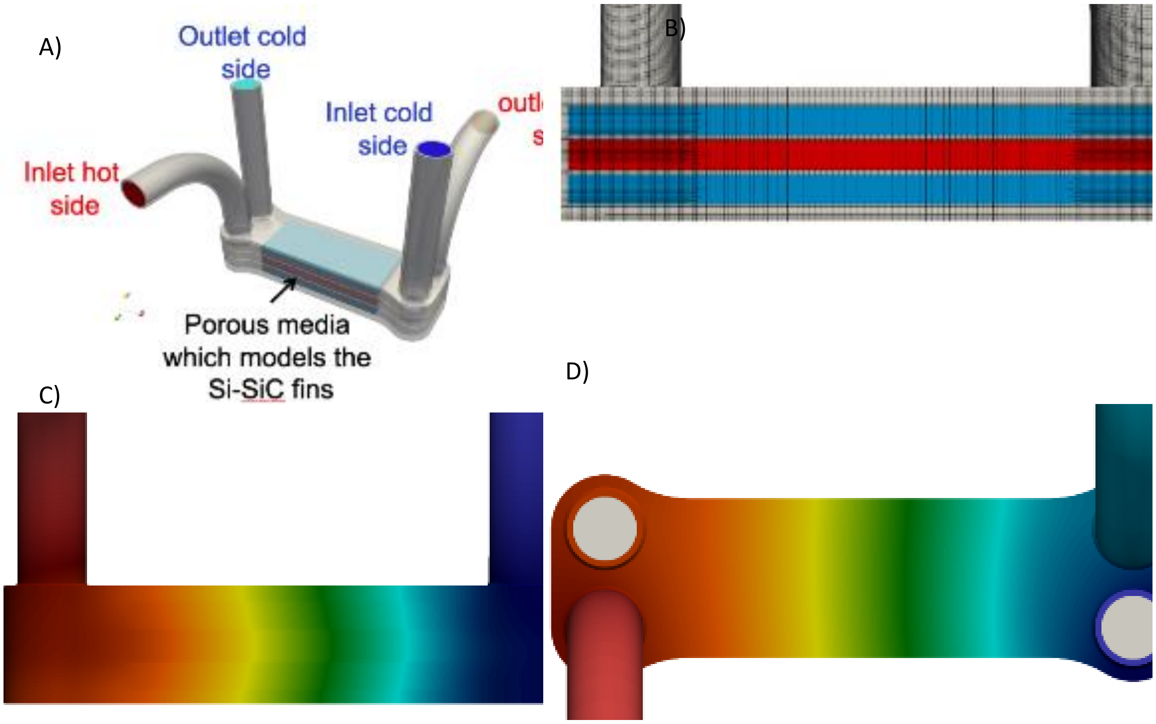

Figure 2. A) External view of the scaled HX prototype. B) Internal channel. C)-D) front and top view of the temperature profile of the solid structure.

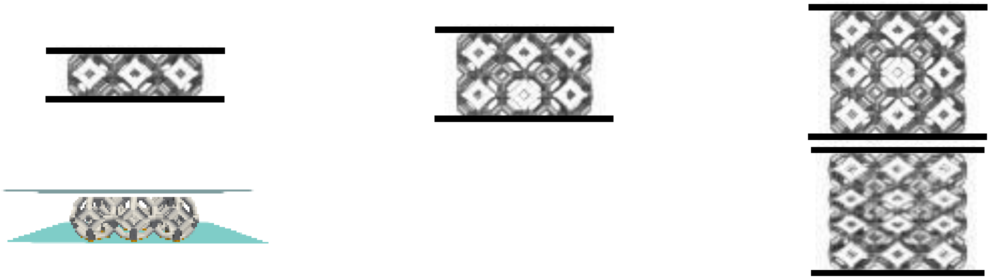

Figure 3. Frontal views of different Lattice core subdomains used for deriving correlations and study the radiation impact on the overall heat transfer

Work package 4 deals with the research and the evaluation of candidate materials for performing thermochemical water splitting. Metal oxides that have been proved attractive splitters (materials belong to the ferrite and cerium family) are shaped into various forms, including traditional structured bodies such as honeycomb monoliths and foams, as well as novel lattices architectures employing advanced manufacturing methods. The new regular cell structures are manufactured with a negative additive manufacturing technique (coating of 3D printed polymeric templates) and are presented in Figure 4. The developed structures are compared to identify the optimum material for the process. Until now, the $NiFe_2O_4$ coated on ZrO_2 foam exhibits the best performance among the various samples.

Apart from the new materials/structures investigated, the durability evaluation of $NiFe_2O_4$ coated on ZrO_2 foam, with respect to water splitting and H_2 production during consecutive splitting and regeneration cycles, is studied (Figure 5). This foam is currently installed at the solar platform, thus the experimental campaign of HYDROSOL-beyond has been relied on the specific material. The target is to investigate the aging effect for over 1000 cycles. Until now a total of 134 cycles has been achieved, which corresponds to ~245h of operation.

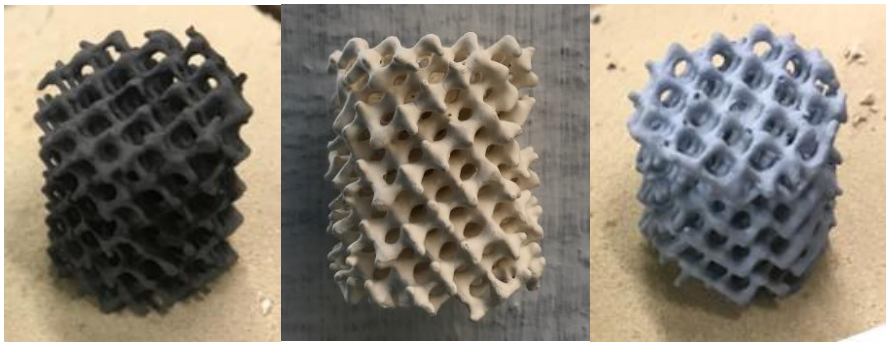

Figure 4. Indicative samples of redox materials developed by 3D printing.

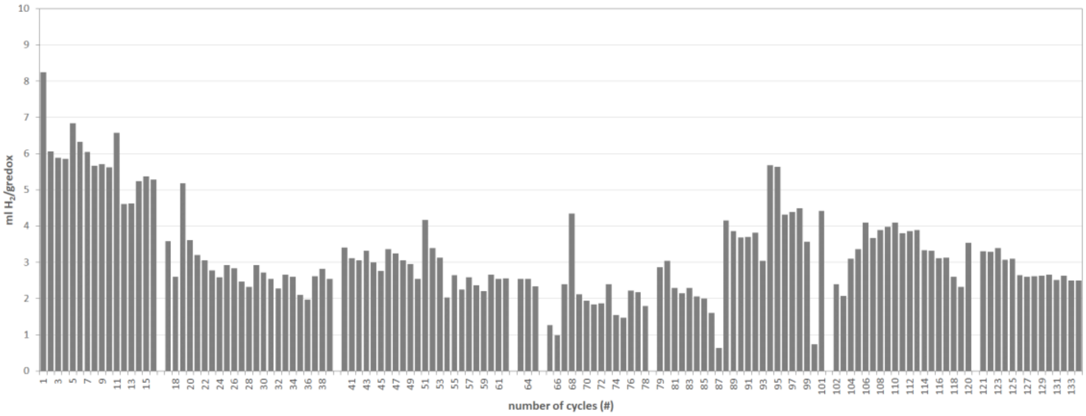

Figure 5: Long-term multi-cyclic assessment of $NiFe_2O_4$ coated foam

WP5 contains the activities regarding the reactor re-design and its integration in the new plant lay out. Initially the repair of the dome-shaped cavity reactor, involving the replacement of the quartz window with a window of alternative geometry, has been performed. Subsequently, the re-visited reactor has been experimentally tested in the solar simulator at Jülich, Germany. The tests have shown an inhomogeneous temperature distribution inside the surface of the receiver, possibly inherent to the geometry of the reactor. Further actions are undertaken to improve the incoming energy flux distribution and the performance of the volumetric absorber. At the same time, the indirect heated reactor concept is investigated. The computational tools that have been developed provide significant insight of the nature of the process and valuable information of the critical parameters impacting the performance of the reactor. The analyses of the kinetic mechanism and the transport phenomena (heat and mass transfer) occurring inside the reactor reveal the absorbers behavior under the operational protocol of the thermochemical water splitting. Finally for a full-scale assessment of the reactor performance the overall system efficiency is estimated taking into account the peripheral components, the various sub-processes and the auxiliary units that are present.

The solar platform had not been operated for over a year, since the end of the previous HYDROSOL-Plant project. Consequently, maintenance actions had to be immediately undertaken as well as activities in order to restore and repair the malfunctioned equipment. These tasks are part of WP6. The efforts have focused mainly on repairing the secondary concentrators placed in front of the reactors. Apart from that, the insulation and the re-design of the window aperture and its subsequent coupling with the flange of the reactor has been successfully completed (Figure 6). After the preparatory actions, a preliminary experimental campaign has been performed.

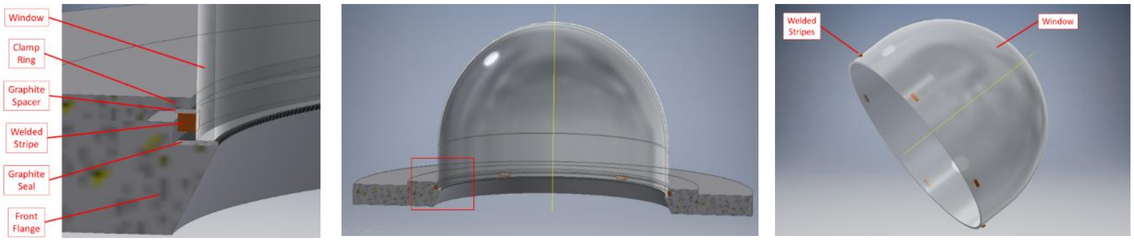

Figure 6. Window modified design with welded stripes.

Finally ray tracing simulations examine the energy flux distribution at the front face of the solar receivers, according to the features of the optical field of the platform. Figure 7 shows the flux distribution of the hexagonal concentrators, at the inlet and outlet surfaces. The flux distribution is clearly more homogeneous in the outlet rather than in the inlet plane, revealing the role played by the CPC.

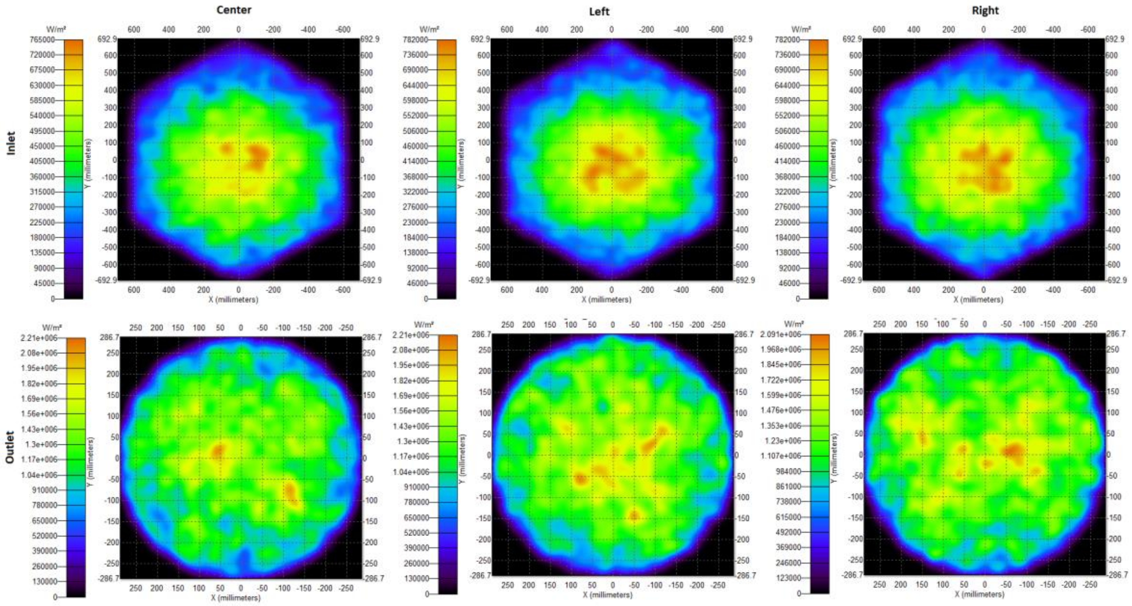

Figure 7. Flux distribution of the hexagonal concentrators, at the inlet and outlet surfaces, for three different aiming points

Within work package 7, the experimental hydrogen production campaigns were taken prior to the modifications and additions of new components to the plant layout. This task has been an essential step of the project in order to identify the operability of all existing hardware and software, to establish the limitations and bottlenecks of the existing configuration via exposure tests of adequate duration and to define the baseline operation of the plant prior to the upcoming modifications.

The testing campaign demonstrates that the receiver shows a short start-up and a fast response to operational conditions changes, indicating low thermal inertia of the system. This preliminary thermal testing also provides valuable information on the general thermal behavior of the cavity and helps to define and optimize a control strategy by studying the influence of process parameters.

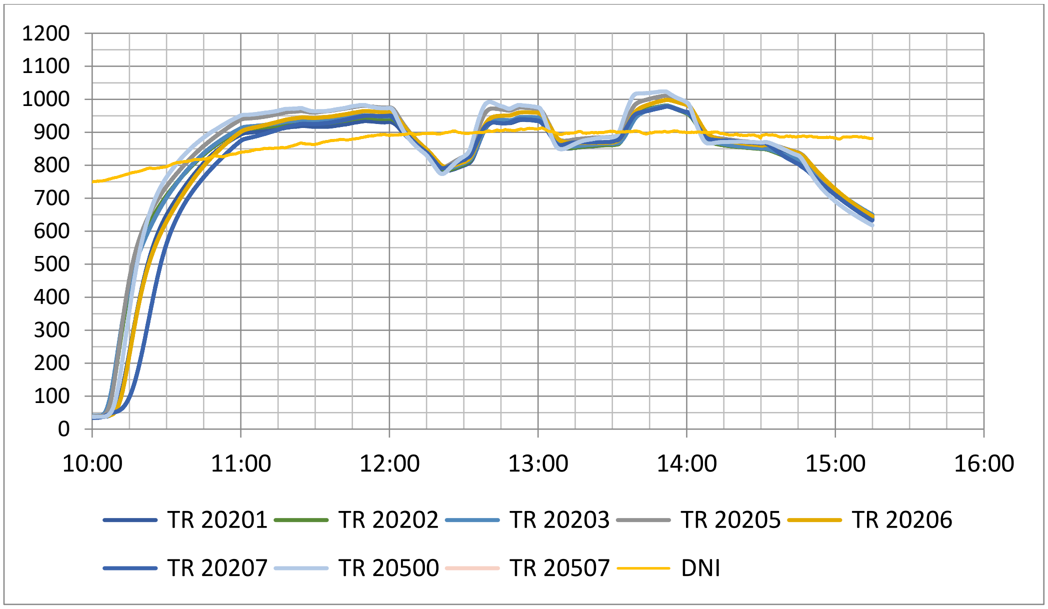

Figure 8. Temperature evolution of the cavity segments in two consecutive cycles.

Although the average temperature profile of the receiver has a very smooth behavior (Figure 8), a visual inspection of the absorber after the end of the tests has reveal significant damages and deterioration in several bricks of the solar reactor.

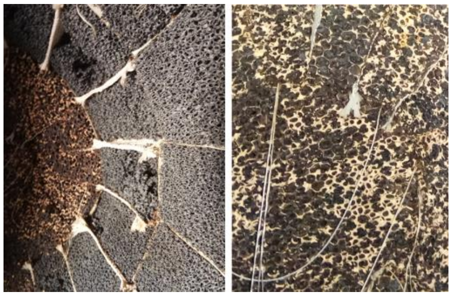

Figure 9. West absorber after the first testing campaign

Figure 10. Details of the segments II and V of the cavity showing the colour change

The structural problems have a triggered a discussion between the partners to identify the causes of these issues and adopt appropriate actions that will be undertaken during the second phase of the project in order to ensure the stability and the high performance of the solar absorbers.

The feasibility and the further commercialization of the proposed technology is evaluated in WP8, where a techno-economic study and a Life Cycle Assessment of the solar platform in Almeria are conducted. Since the plant was not operable during the first year of the project, the partners responsible for these tasks have started the analyses based on the collected data from the previous Hydrosol-Plant project.

For WP8 “Techno-economic study-LCA study”, one of the main achievements is that a first LCA has been performed with the Hydrosol-Plant data. The LCA of HYDROSOL-beyond will be carried out in the next period when the data from the process improvements will be available. The purpose of carrying out the LCA of Hydrosol Plant is to compare it with the HYDROSOL-beyond and evaluate the impact of modifications in the plant efficiency. For the techno-economic assessment, it has been decided to base the analysis on a representative industrial power plant.

Finally WP9 regards the Dissemination and Exploitation activities taken both during the HYDROSOL-beyond and after the end of the Project. All exploitation actions will proceed in parallel and will interact with the dissemination activities. For this reason, both strategies are examined as a single entity. The involved partners have already provided an updated and more detailed Plan for the Exploitation and Dissemination of occurring Results, explaining how they intend to further exploit and disseminate both the preliminary and the oncoming results. Additionally, related dissemination activities such as scientific publications and conferences participation have also be taken. Finally, regarding exploitation, the three dominant Key Exploitation Results (KERS) of this project have been identified in order to exploit the scientific results and a preliminary roadmap has also been developed.

History of Changes		
Version	**Publication Date**	**Change**
1.0	01.03.2021	Initial version
1.1	04.03.2021	Correction of the 1st version based on officer's comments. Update the template with valid funding logos and document structure enhancement.