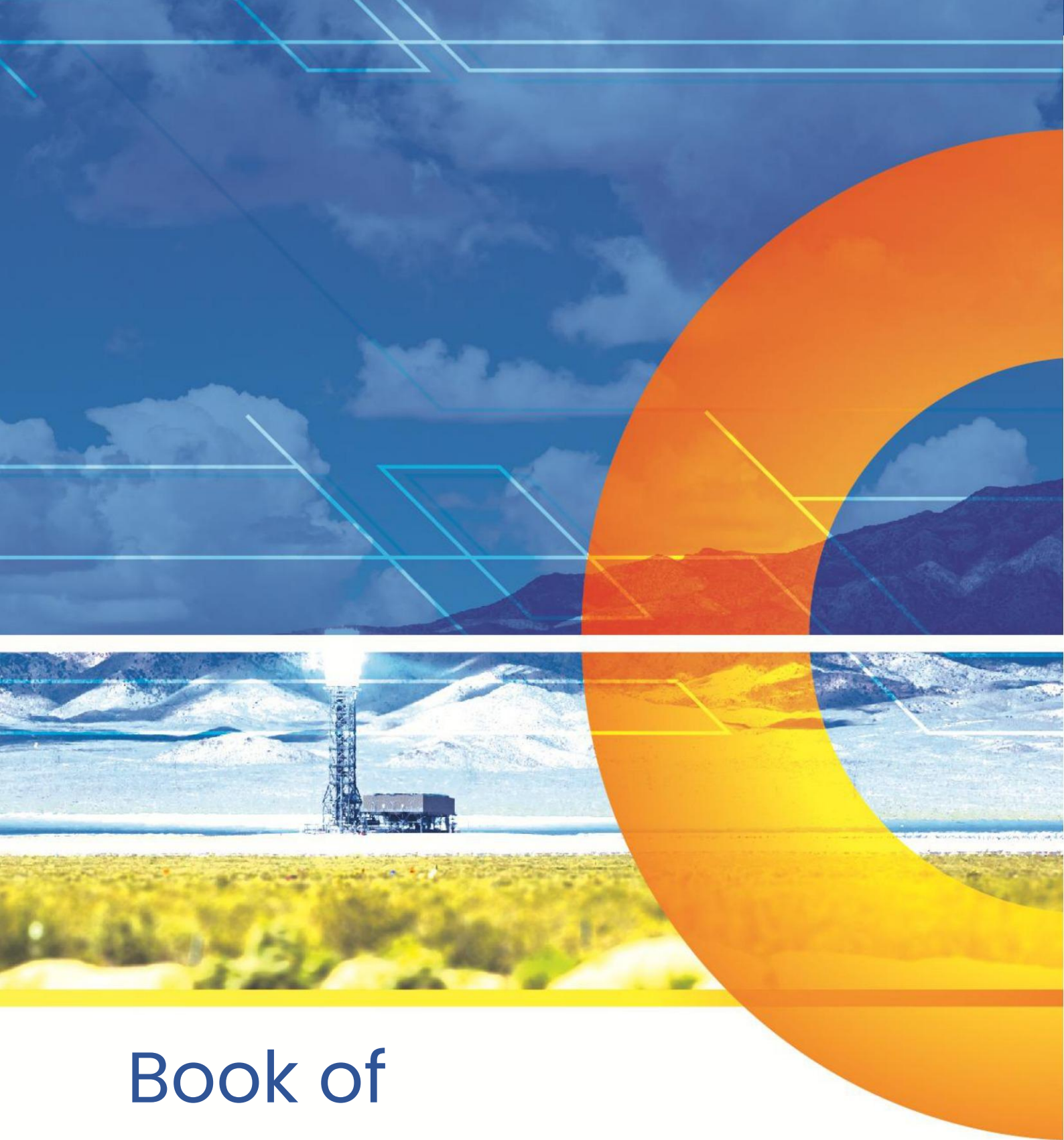




Book of ***ABSTRACTS***

EU-Solaris 3rd Doctoral Colloquium 2026, Nicosia, Cyprus



Foreword

It is a great pleasure to welcome you to Nicosia for the 3rd EU-SOLARIS Doctoral Colloquium, hosted this year by *The Cyprus Institute* from 19 to 21 October 2026 and followed by the 2nd EU-SOLARIS Summer School on 22–23 October.

In only a few years, the Doctoral Colloquium has become a valued tradition of the Concentrating Solar Thermal (CST) community. This third edition brings together 25 doctoral contributions from research centres and universities across Europe and the Mediterranean, organised in six thematic sessions: line-focusing systems and field performance; point-focusing systems and solar resource; solar thermochemical redox and electrolytic processes; thermochemical storage, commodities and biofuels; thermal energy storage, power-to-heat and hybridisation; and solar heat for industry and water. The abstracts collected in this book reflect the breadth of today's CST research, from optics and receivers to solar fuels, energy storage and water treatment.

For Cyprus, hosting this event is particularly meaningful. Cyprus takes part in EU-SOLARIS ERIC through The Cyprus Institute and its *PROTEAS* research facility at Pentakomo, on the island's south coast. *PROTEAS* was conceived as a testbed for small-scale CST systems suited to islands and coastal regions, combining a heliostat field and a central tower receiver with molten-salt thermal energy storage and thermal seawater desalination. I look forward to welcoming you there during the Colloquium, to see first-hand how CST can support the polygeneration of heat, electricity and fresh water under Mediterranean conditions.

Gatherings such as this one are made possible by the *SOLARIZE* project, funded by the European Union, and by the continued commitment of the EU-SOLARIS partners. They serve the mission of EU-SOLARIS ERIC: *"To strengthen the cohesion of the R&D community in CST."* Above all, they give early-career researchers the opportunity to present their work, receive constructive feedback and build the connections that will shape the future of our field.

I wish all participants a stimulating colloquium, fruitful discussions and an enjoyable stay in Nicosia.

With warm regards and a heartfelt welcome to Cyprus,
On behalf of the Organising Committee.

Dr. Marios C. Georgiou
Head of the *PROTEAS* Research Facility
The Cyprus Institute
Vice-Chair, EU-SOLARIS ERIC General Assembly

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Disclaimer

This book brings together doctoral research in progress, shared in the spirit of open exchange that defines the Colloquium. The abstracts are presented as provided by their authors, ahead of the scientific review process, and each reflects its authors' own perspective.

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Toward Predictive Modeling of Molten-Salt Drainage in Parabolic-Trough CSP Systems

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Keywords: molten salt, parabolic trough, CSP, drainage, freeze risk, thermo-hydraulic modelling

Molten-salt parabolic-trough concentrating solar power systems are a promising development of conventional thermal-oil-based technology, as they allow higher operating temperatures and enable direct integration with thermal energy storage. However, the elevated freezing temperature of nitrate salt mixtures introduces additional operational challenges. In particular, reliable drainage of the solar field becomes a critical procedure during maintenance, shutdown, freeze-protection, and emergency scenarios.

Drainage in molten-salt parabolic-trough systems cannot be regarded as a purely hydraulic emptying process. Instead, it is governed by a coupled interaction of hydrostatic driving forces, gas-liquid interface dynamics, pressure redistribution, temperature-dependent fluid properties, heat losses, residual liquid hold-up, and possible solidification. Even after nominal drainage, remaining salt films, stratified liquid tails, and geometry-induced hold-up may continue to cool and crystallize in critical regions such as receiver tubes, headers, crossover sections, valves, and drainage lines. This can lead to flow restrictions, freeze-plug formation, and operational risks during subsequent restart procedures.

The present doctoral research addresses the need for a predictive understanding of molten-salt drainage in parabolic-trough solar fields. As a first step, a systematic review is being conducted to consolidate the available knowledge from molten-salt CSP applications, pipeline drainage, two-phase flow, liquid hold-up, thermo-hydraulic modeling, and solidification studies. The objective is to identify the dominant physical mechanisms, relevant modeling approaches, and current limitations for predicting drainage behavior under realistic operating conditions.

Based on this review, the research aims to derive the requirements for a transient thermo-hydraulic drainage model capable of assessing drainage duration, residual salt inventories, temperature evolution, crystallization risk, and drainage success or failure for different loop designs and boundary conditions. Such a model would support the evaluation of critical operating scenarios, the identification of freeze-prone regions, and the development of improved drainage strategies for future molten-salt parabolic-trough systems.

This contribution presents the current research framework, the identified knowledge gaps, and the planned modeling direction of the ongoing doctoral project.

A hybrid beam-down linear Fresnel concentrator for heat and electricity production

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Beam-down concentrated solar power systems are innovative technologies that redirect the solar irradiation to the ground rather than collecting it on specific linear or point focal receivers located at a specific height [1]. This design has been proposed aiming to reduce the levelized cost of energy of conventional concentrated solar power systems throughout reducing the initial investment cost and also the potential operational and maintenance costs [2]. Beam-down systems offer several advantages in comparison to the conventional one, regardless of the type of the concentrated solar power system. First of all, the system is more stable, safe, and reliable since the receiver is stationary, which means it is not moving or rotating, and also it is easier to maintain since it is located on the ground, meaning it is more easily accessible [3]. Second, the pumping demand is significantly reduced since there is no need to circulate the heat transfer fluid on a specific height thus reducing the pressure drop that the pumping system has to cover. Furthermore, the pipeline configuration is significantly simplified due to the absence of vertical pipes, ninety-degree junctions, and other specific elements since the pipes that circulate the heat transfer fluid are horizontal and located close to the ground [1]. Third, in most of the cases, the total height of the system is reduced, which means that the overall construction is more compact, and wind loads are expected to be lower [4]. However, due to the existence of an extra reflector, the overall optical efficiency is reduced. This is the most critical drawback of beam-down concentrators [5]. All the aforementioned make beam-down technologies an interesting subject for research aiming for the best designs that balance the drawback of the excess losses over the benefit of simpler and lower cost constructions.

Hybridization of concentrated solar power systems seems to be another step forward towards further reducing the levelized cost of energy produced [6], and this observation also applies to beam-down configurations. In this direction, a new beam-down linear Fresnel concentrator configuration is proposed, with a triangular-shaped secondary reflector, aiming to increase the energy density of the collector by exploiting the previously unexploited surface area of the beam-down secondary reflector. The triangular design of the secondary mirror aims for two separate improvements for the system. First of all, the construction cost of the triangular mirror is significantly lower than the cost of a hyperboloidal or a parabolic mirror, which present the highest performance according to the existing literature

[5]. Second, it allows the proper integration of conventional photovoltaics onto the upper surface of the mirror. On the other hand, the total weight of the secondary reflector increases, thus increasing the construction cost and required material for the supportive structure where the secondary mirror has to be mounted. However, the addition of photovoltaics can generate electricity that can either be supplied to the grid, stored locally, or used for covering the needs for self-consumption of the collector, especially for driving the pumps. These observations could potentially lower the total operational cost of the beam-down linear Fresnel concentrators, and thus it is an interesting research topic for the research community that deals with concentrated solar power systems. **Fig.1** illustrates the conceptual design of the hybrid beam-down linear Fresnel collector.

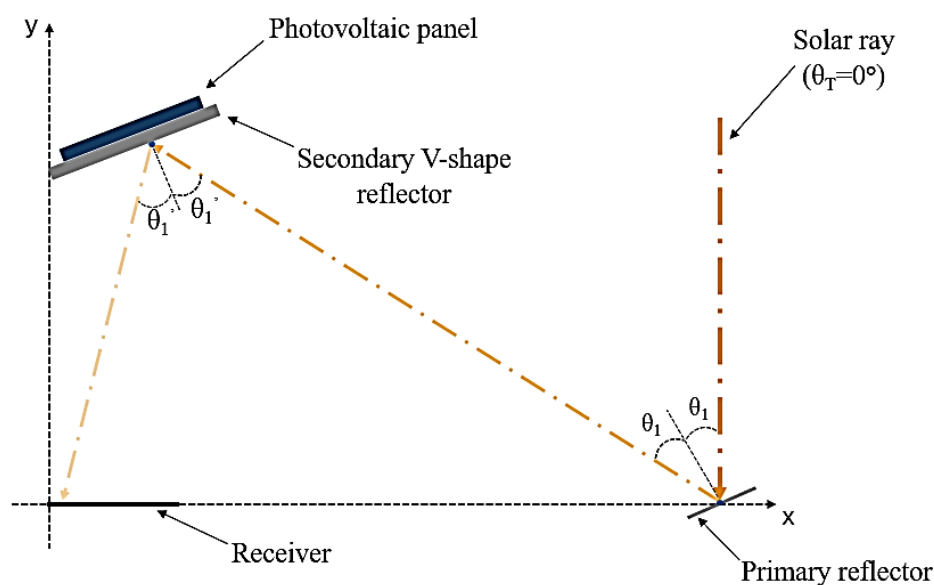


Fig.1 : The conceptual design of the proposed hybrid beam-down linear Fresnel collector for heat and electricity production.

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The influence of angle of incidence on soiling measurements

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The fast growing of solar fields around the world is accompanied by a best understanding of the main parameters that affect these renewable systems, as irradiance, temperature and soiling. The last one is a natural and random phenomenon that influences the performance of concentrating solar thermal (CST) and photovoltaic (PV) systems. The continuous monitoring of the soiling effect in solar systems is highly recommendable. This monitoring is performed with different sensors, depending on the solar technology installed. The angle of incidence (AOI) plays an important role in the soiling ratio measurement for PV systems. The transmittance of light through a soiled surface relative to a clean one depends on the AOI, as higher AOI values result in increased light obstruction for the same level of surface soiling. The accumulation of dust or other contaminants on the module surface leads to a change in the optical behavior of the air-glass interface. The effect of AOI becomes more pronounced with increasing particle density, as a larger fraction of the incident light is absorbed or scattered by dust particles [1]. The main objective of this work is to improve the soiling losses measurements of PV systems by the incorporation of the angular dependence of the SR into the signals provided by sensors which do not capture this influence.

Figure 1 shows, for two clear-sky days, the soiling ratio values (blue dots) measured by a system consisting on two PV modules, one kept constantly soiled and the other always clean. In addition, the red line represents the result of the parametric model used to capture the angular dependence of the soiling measurements [1]. It can be observed that the model follows the actual behavior of the measurements.

Once the model has been obtained and validated, the correction for the angle of incidence is applied to the soiling ratio values measured with a device which measurement is independent of AOI such as DustIQ.

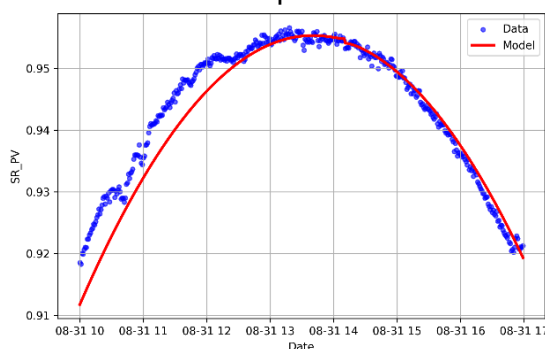
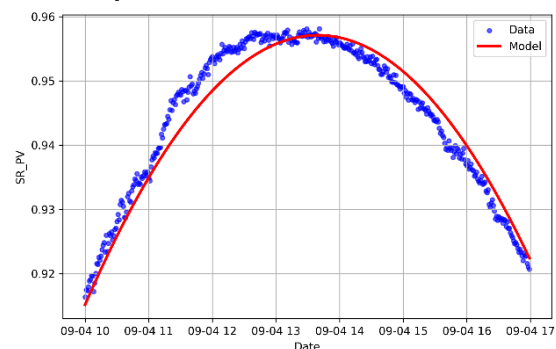


Fig.1 Soiling ratio measured (blue dots) and corrected (red line) correspondent to clear sky days.

Figure 2 shows the soiling ratio values before and after applying the AOI corrections for the rest of 25 clear-sky days within the study period. When comparing the metrics between both cases, it is observed that the corrected data more accurately describe the real evolution of the soiling ratio as a function of AOI. In addition, the RMSD and MAE metrics decrease from 0.040 to 0.019 and from 0.032 to 0.015, respectively. In summary, neutralizing the AOI dependency significantly enhances data quality, making this correction essential for accurately quantifying true soiling losses.

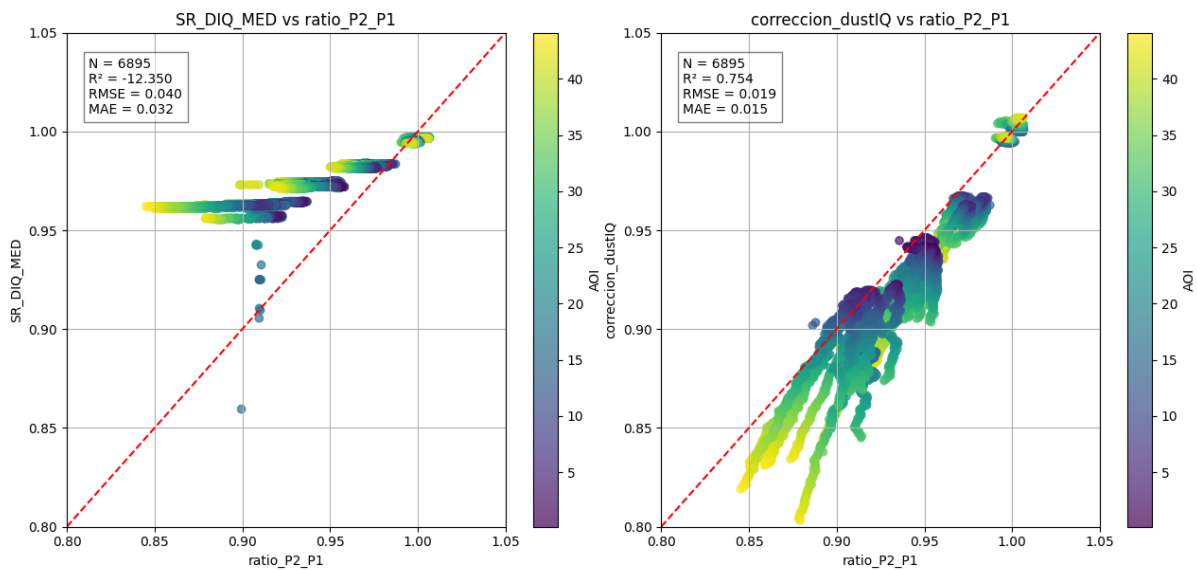


Fig.2 Soiling ratio measurement by commercial sensor. Right graph shows the original data versus the SR calculated with the soiling measurement station. Left graph shows the SR signal corrected by AOI versus the SR calculated with the soiling measurement station.

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Wind Loads on Heliostats: Determining Dynamic Amplification

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1. Introduction

Accounting for up to 50%, the heliostat field represents the largest share of the total investment in concentrated solar thermal (CST) systems [1]. To further reduce the cost of heat production, particular emphasis is therefore placed on optimizing the design of the heliostats. Heliostat design to date has been based on wind tunnel tests with stiff models and rarely take into account the actual site-specific wind characteristics and their dynamic effects [2]. As these effects significantly impact the loading of the heliostat structure [3], corresponding safety factors are currently applied, which, in conservative design, lead to the individual components being oversized. The methodology presented below takes into account the dynamic response of the heliostat and provides the Dynamic Amplification Factor (DAF). This describes the ratio of the maximum response of the static case to the dynamic response at the 50-year maximum.

2. Method

Simultaneously with three-dimensional wind speed measurements using an ultrasonic anemometer, the resulting wind loads on a rigid plate are recorded by differential pressure sensors, as shown on the left and top right in Figure 1. In a Finite Element Method (FEM), the gained pressure time series (Fig.1 bottom right) is applied to the heliostat model under investigation. The calculation is first performed for a static case using a rigid heliostat model. Then, a dynamic FEM simulation is carried out using a realistically flexible heliostat model and taking into account damping properties, resonances and natural modes [4]. The ratio of the dynamic and static maximum responses yields the DAF. By extreme value statistic, the maximum DAF during 50 years is calculated [5].

3. Application

With the help of the workflow and the rigid plate, it is possible to determine the Dynamic Amplification Factor. This allows a site-specific optimization of the heliostat design which leads to a reduction in investment costs.

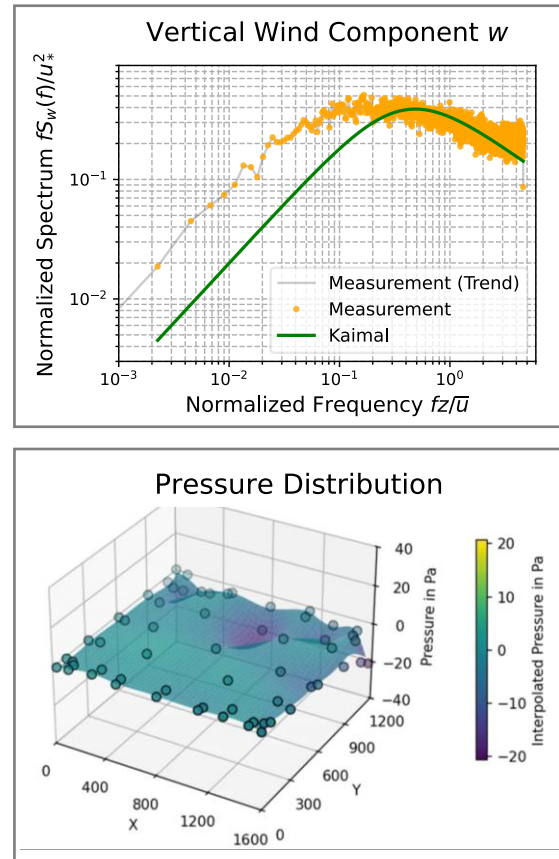


Fig.1: Left: simultaneous measurements using the ultrasonic anemometer and the rigid measurement plate; Top right: Normalized frequency spectrum of the vertical wind component;
Bottom right: distribution of differential pressure time series across the plate.

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Design and Optimization of the Optical Systems for a Beam-Down Concentrated Solar Power Plant

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1. Introduction

The European SUNSON project (www.sunson.eu) [1], [2], aims to develop a CST-powered electricity generation system based on thermophotovoltaics (TPV) and thermal storage using very high-temperature ($>1200^{\circ}\text{C}$) phase change materials (PCM) [3]. Within this framework, this study designs the optical components of a Beam-Down concentrated solar power plant, analyzing their synergy and efficiency. The influence of the hyperbolic reflector eccentricity (e) on the sun-shape reflected onto the receiver is examined, alongside the power obtained at the inlet and outlet of the secondary concentrators (CPC). Furthermore, the incident radiation on each surface of the optical system is evaluated. Finally, based on these considerations, the plant's capacity to capture and concentrate solar energy is evaluated.

2. Materials and Methods

The heliostat field, comprising 13,385 single-facet heliostats (4 m^2 each) with canted focusing, was designed in SolarPilot for a 40 MWth plant capacity. The resulting coordinates, along with CAD-generated geometries for the hyperboloid and CPC, were integrated into TracePro 2024 Expert via macro. This setup employs Monte Carlo Ray Tracing (MCRT) to analyse the solar reflection and absorption processes along all optical components, from the heliostat field to the receiver. This approach enables a comprehensive evaluation of the synergy between components, as well as the radiant flux, incident power, and overall plant efficiency.

3. Results and Discussion

The analysis shown in Fig. 1 demonstrated that the eccentricity e does not significantly affect the overall secondary transfer efficiency. For low e values, $M>1$ indicates receiver spillage due to a magnified solar image relative to the aim point. As e increases, the energy concentrates into a smaller spot ($M<1$) before exceeding $M>1$ again at $e = 14$. Furthermore, although total receiver power remains stable at low e , it eventually drops as the increasing hyperboloid area begins to shade the heliostat field. Consequently, the power per square meter on the hyperboloid decreases as e increases, evidencing lower utilization efficiency at higher eccentricities. Additionally, Fig. 2 shows that while the power at each CPC outlet decreases for low e values, the flux distribution becomes more uniform across the CPC array.

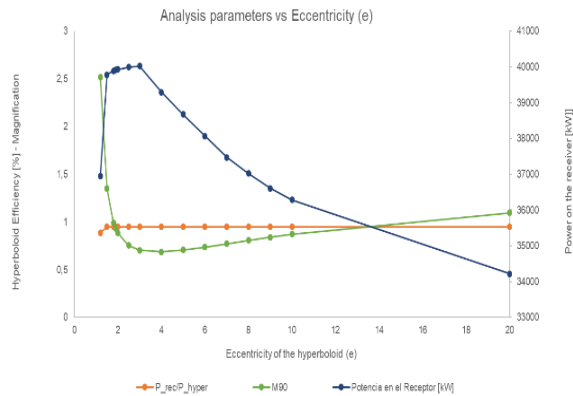


Fig. 1: Hyperboloid efficiency, magnification and power on the receiver as a function of the eccentricity of the hyperboloid.

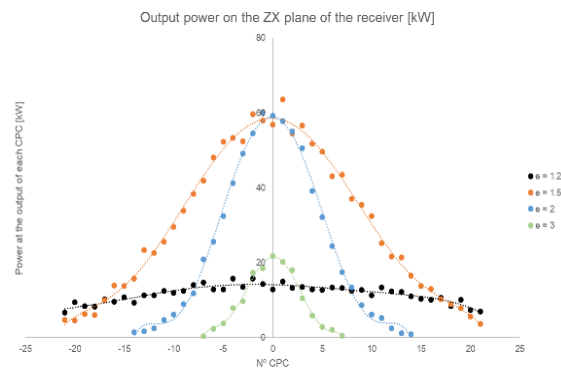


Fig. 2: Power at the CPC output as a function of the number of CPCs.

4. Conclusions

In this study, maximizing the concentration on the hyperboloid is not always desirable, as high flux densities would require active cooling of the secondary reflector. Instead, operation under a controlled magnification regime is preferred, which reduces the thermal load on the hyperboloid and shifts the concentration to the lower receiver using secondary optical systems. This approach introduces a new design criterion based on balancing optical performance and thermal management, aiming for more efficient overall system configurations.

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Design optimization of an Open Volumetric Air Receiver via CFD analysis of porous absorber and passive flow regulation system

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1. Introduction

Within the framework of ASTERix-CAESar, the design of the receiver of the central, which is based on the design of the CAPTURE project [1], is being optimized. The concept relies on segmentation of the receiver in modules and is improved to include a passive built-in flow regulation system to solve the issues caused by high-gradient flux patterns. This issue consists in that the majority of the flux intensity is concentrated in the center while the corners of this rectangular receiver are exposed to less intensity, which leads to high gradients of temperature of the receiver material and in the outflowing stream. The flow regulation solves the lowered thermal efficiency that is caused by the inhomogeneous stream. However, the number of modules it must be divided into is to be determined, as it would be a trade-off between improved efficiency, production costs tied to the amount of single-piece modules, and long-term mechanical stability. This study carries out that analysis and is a follow-up of the previously presented work, which developed the 3D model implemented in this contribution in STAR-CCM.

2. System Description

The open volumetric air receiver (OVAR) used for this project is of 1.00x0.70 m dimensions and is composed of SiC absorber and ceramic oxide cup modules, Fig 1 a). The design consists of 35 140x140mm receiver modules, each with air-funneling cups that serve as a holder for the SiC ceramic foam and as a flow stabilizer. It is improved upon by adding throttling diaphragms to the 89 mm wide outlets to impede the flow for the lateral and corner cups, which receive a lower irradiance, Fig. 1 d). Four designs are proposed, reducing the number of units to be produced, and with it the costs. Case 2 and 3 are selected for analysis, with 4x4 and 3x4 arrays respectively.

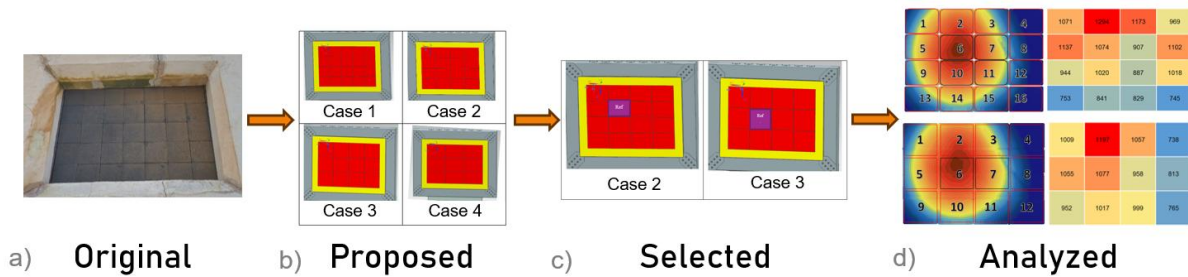


Fig.1: Schematic summary of design optimization process of the new receiver. a) The original design with 5x7 rows and columns. b) Proposed segmentation designs. c) Selected cases to be analyzed with the reference module marked. d) Left, solar flux map of the receiver, and cup outlet type in black and red for unchanged and reduced outlet diameter, respectively; right, resulting map of temperatures.

3. Numerical methodology

The pilot plant design targets an 800 °C air output. The module receiving the highest heat flux is set as the reference case with no flow restriction. Corner and side modules incorporate flow-restricting diaphragms, whose diameters must be determined and is the focus of this study, in order to fulfill target and physical requirements. Design parameters were determined through successive constraints to obtain it. Firstly, the mass flow rate (mFR) and pressure drop (ΔP) of the center reference case were determined to obtain $T_{air,out} = 800$ °C. Since all modules in a receiver share the same ΔP_{drop} , this value becomes a requirement for the remaining modules. A range of outlet diameters were tested against the appropriate mFR for a reference corner module with the highest incident heat flux to achieve the correct ΔP_{drop} . Of these, the geometry that lead to an outlet temperature of 800 °C was selected as the design set point for rest of the lateral cups. This process was applied to Cases 2 and 3, Tab. 1.

Modules receiving the highest heat flux (black) have no diaphragm, while those marked in red have the designed reduced outlet diameters. Figure 1 d) shows the theoretical resulting temperature distribution of the entire receiver during operation for each case. Thermal yield of all modules was calculated to determine total receiver performance.

Table 1: Design parameters for the considered cases. The reference center module measures in the second and third columns, and the determined conditions to fulfill the design requirements and objectives in the fourth and fifth columns.

Simulation	Center cup CASE2	Center cup CASE3	Corner Cup CASE2	Corner Cup CASE3
Orifice Diameter	89 mm	89 mm	62 mm	65 mm
Incident Flux, P_{inci}	31395 W	40801 W	24528 W	32211 W
mFR	0.02926 kg/s	0.0373 kg/s	0.02252 kg/s	0.0289 kg/s
Pressure drop	297 Pa	365 Pa	299 Pa	371 Pa
$T_{Air,Out}$	1074.4 K	1074.4 K	1071.0 K	1071.6 K

4. Conclusions

This study optimizes the project's receiver design integrating a flow throttling diaphragm at the module outlet to address flux gradient issues causing temperature inhomogeneities. Two configurations (4×4 and 3×4 arrays) are studied. Outlet diameters of 62 mm and 69 mm lead to thermal efficiencies of 77.9% and 76.1% respectively. Thus, the 4×4 design shows an improvement in thermal efficiency of 1.9% points over the other.

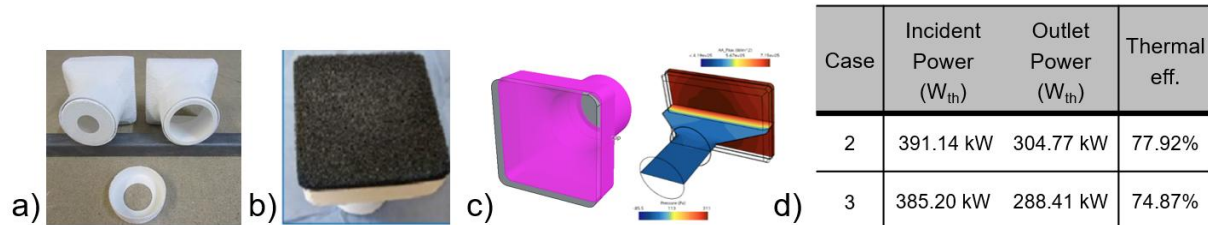


Fig.2: Images of the receiver modules and results. a) The outlet diaphragms for flow throttling, b) front view of the absorber-cup ensemble, c) numerical model with the highlighted cup-region and the calculated pressure drop, symbolical for the model execution, d) thermal performance results of the designs.

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Design of Experiments for the Development and Optimization of SiC/Al₂O₃ Multilayer Coatings for High-Temperature CSP Receivers

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The development of high-temperature concentrated solar power (CSP) receivers requires protective coatings combining oxidation resistance, mechanical stability and suitable optical properties under severe thermal conditions. In this study, a hybrid system consisting of a Fe–Cr–Al–Mo alloy substrate (Kanthal APMT), an α -Al₂O₃ interlayer and a SiC coating was investigated (Fig.1). The alumina interlayer was obtained by thermal pre-oxidation of the metallic substrate and was introduced to improve the compatibility between the metallic substrate and the ceramic coating. SiC coatings were deposited by high-temperature chemical vapor deposition (HTCVD), a process known to produce dense polycrystalline SiC coatings under appropriate growth conditions [1], [2].

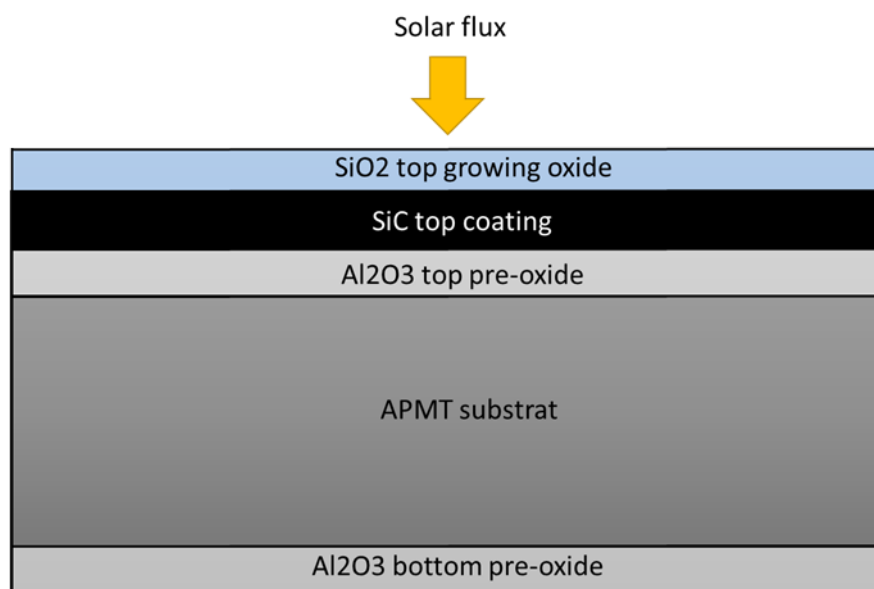


Fig.1: Representation of the multilayer

Following a first deposition campaign, a design of experiments (DOE) was implemented to identify the main deposition parameters governing coating quality. Seven factors were investigated using a Plackett–Burman screening design [3]: alumina thickness, SiH₄/C₃H₈ precursor injection sequence, deposition temperature,

with NH_3 (yes or no) , presence of a second deposition step, number of SiC/Si/SiC sequences and total deposition time. Coating delamination, SiC thickness and residual stress were selected as the primary responses.

The DOE analysis showed that the precursor injection sequence, alumina thickness, number of SiC/Si sequences and deposition time were the most influential parameters. In particular, injecting SiH_4 before C_3H_8 favoured coating adhesion and growth, whereas the reverse sequence promoted delamination. A deposition temperature of 1200 °C, an alumina thickness of approximately 1 μm , no NH_3 addition and a deposition time of 30 min provided a favourable compromise between coating thickness and adhesion. Under selected conditions, SiC coatings with thicknesses of approximately 11–13 μm and very low delamination were obtained.

The most promising coatings were characterized by scanning electron microscopy, FIB cross-sectional imaging, EDS, X-ray diffraction, residual-stress measurements and radiative-property measurements. The coatings exhibited a dense and homogeneous microstructure, continuous interfaces and predominantly compressive residual stresses ranging from approximately -2.18 to -2.85 GPa. Solar absorptivity ranged from 83.9 to 87.9%, while total emissivity varied from 58.9 to 66.0%. These results demonstrate the potential of the developed SiC/ Al_2O_3 /APMT multilayer system as a solar-absorbing coating for high-temperature CSP receivers.

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Multi-Modal Generative Video Prediction of All-Sky and MSG/MTG Satellite Imagery for Solar Irradiance Nowcasting

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1. Introduction

The transition to green energy requires solar power generation to overcome production fluctuations caused by local cloud variability. Accurate, high-spatiotemporal-resolution solar irradiance forecasting is essential for reliable thermal management and operational scheduling in CSP/CST plants [1].

Recent breakthroughs in generative video prediction have demonstrated strong performance in capturing cloud dynamics. Models trained on satellite [2, 3] or all-sky-imagers (ASI) [4, 5] have each set new forecasting benchmarks at their characteristic spatiotemporal scales. Efforts have since blended the disparate data [6, 7] or trained unified multi-modal frameworks to leverage both sources' strengths [8].

As a continuation of this work, we present a multi-modal video predictor that simultaneously forecasts future image frames and irradiance time series. This abstract evaluates preliminary results of a model variant based exclusively on Meteosat Second Generation (MSG) geostationary satellite data, with the outlook of integrating ASI data as an additional input.

2. Methodology

Following [3], we pre-processed a 3-channel MSG product consisting of the cloud index (CI) and the 10.8 and 3.9 μm infrared (IR) bands. MSG data spanning 2020–2025 is cropped to 128×128 pixels, centred on the Eye2Sky cloud observation network in Oldenburg, Germany [9]. Irradiance measurements, e.g. Global Horizontal Irradiance (GHI), are averaged to 15-minute intervals to match MSG's temporal resolution. The stratified split (two random days per month for validation, one for testing; ~90/7/3 ratio) ensures seasonal representation, with 2-hour context and 1-hour prediction horizons.

Our framework implements the Frame-Autoregressive Model (FAR) [10]. It utilizes the Deep Compression Autoencoder (DCAE) from [11] to encode images in pixel space into a low-dimensional latent representation. The latent representation is then propagated forward in time by a diffusion transformer-based video predictor and decoded via a dual-task decoding scheme: one branch reconstructs the MSG product, while a second head maps to a target irradiance component. Fig. 1 summarizes the model architecture.

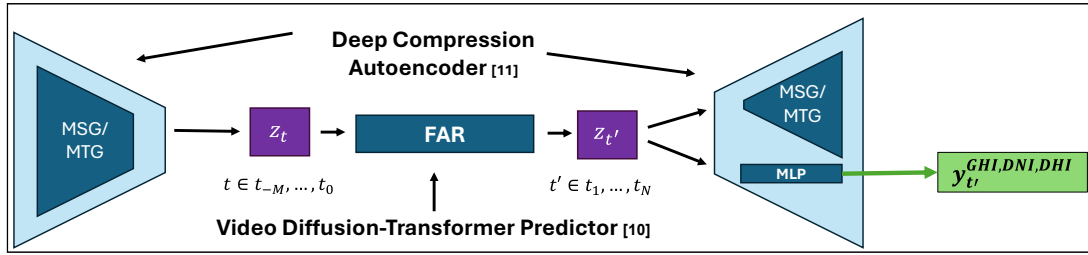


Fig.1: Proposed model architecture. MSG cloud index images pass through the DCAE and FAR's diffusion-transformer video predictor, with the DCAE enabling simultaneous decoding of both MSG imagery and irradiance time series.

3. Results

Model performance on the test dataset is evaluated in Fig. 2. Panel a) shows that image-quality metrics degrade with increasing lead time, although the model captures general cloud advection well. Panel b) presents the GHI prediction errors, which remain relatively large. In terms of forecast skill, however, panel c) shows positive skill relative to persistence at higher lead times, validating the model's potential. Finally, panels d) and e) show exemplary predictions of cloud index and corresponding GHI, revealing a key strength of the simultaneous prediction framework: the physically consistent relationship between predicted cloud coverage and irradiance enables explainable model outputs.

We associate the current performance limitations, particularly the model's difficulty in predicting newly emerging cloud structures to overfitting on the test dataset. Incorporating more diverse training data should improve generalization. In addition, future model versions will include the solar zenith angle as an input, which is expected to improve the learning of cloud-shadow projection and, consequently, irradiance prediction.

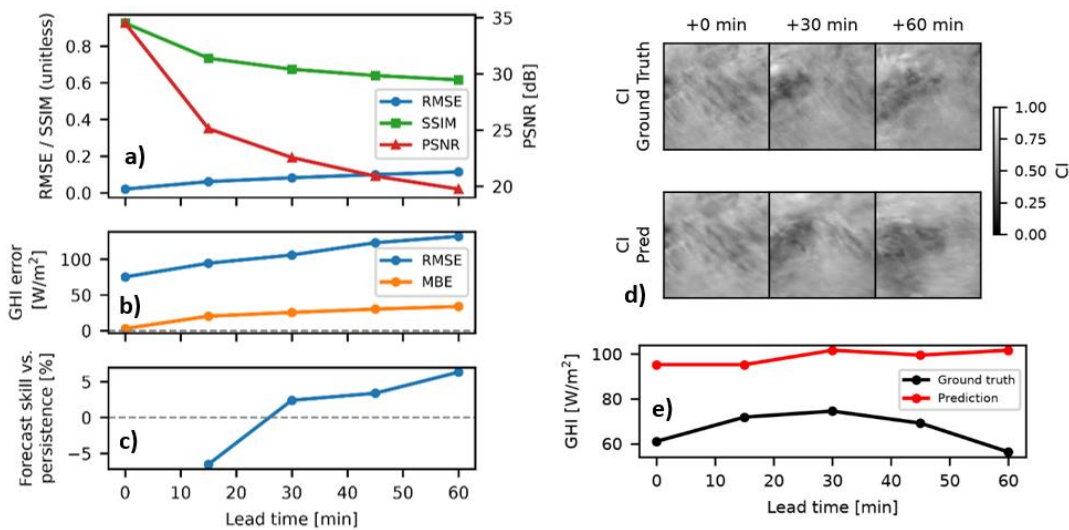


Fig.2: Model evaluation on the test dataset. **a)** yields the image metrics RMSE, Structural Similarity Index (SSIM) and Peak Signal-to-Noise Ratio (PSNR), and **b)** reports RMSE and mean absolute bias (MBE) of predicted GHI as a function of lead time. In **c)** the forecast skill relative a persistence model is plotted. **d)** shows a sample's predicted cloud index frames and **e)** the corresponding ground truth and forecasted GHI.

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Techno-economic optimization of fuel production from solar thermochemical redox cycles

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Recent studies highlight the need for diversifying low-emission fuel pathways to meet the growing energy demand in hard-to-abate sectors [1], [2], [3], [4]. In a net zero scenario, the IEA estimates the demand for hydrogen-based fuels in 2050 to be 151 Mtpa [5]. Low emission hydrogen production from projects that are operational, under construction or have reached final investment decision is projected to reach 4.2 Mtpa by 2030 [6]. It is not yet clear which technology or technology mix will be dominant in closing the gap between future hydrogen demand and current supply capacities.

Among low-emission fuel options, biofuels currently have the greatest commercial presence and account for approximately 2% of global fuel consumption; however, approximately 98% remains fossil-based [5]. While advanced biofuel pathways can use waste and residual materials, feedstock availability and potential environmental impacts constrain their large-scale deployment. Electricity-based synthetic fuels represent an alternative option, but require substantial electricity supply and corresponding infrastructure.

A third, less extensively investigated option is represented by solar fuels. In this work, solar fuels are defined as synthetic liquid or gaseous fuels produced through thermochemical processes that directly convert concentrated solar thermal energy into chemical energy, without intermediate electrical conversion. Unlike electricity-based e-fuels, which rely on renewable power for electrolysis or CO₂ reduction, solar fuels rely on high-temperature solar heat from concentrated solar thermal energy harnessed by solar reactors – typically supplied by solar tower systems – to drive endothermic reactions such as the splitting of CO₂ and H₂O into CO and H₂ respectively or the co-splitting into syngas [7]. These intermediates can then be converted into fuels such as methanol, methane or Fischer-Tropsch fuels in a downstream synthesis.

One DLR-developed solar reactor concept is the monolithic receiver-reactor with multiple mobile redox units which makes use of solar thermochemical redox cycles in a two-step process using ceria as solid metal oxide [8]. In the first step, ceria is reduced at operating temperatures of around 1500 °C and oxygen is released. In the second step, the ceria is cooled to approximately 900 °C and oxidizes with CO₂ and/or H₂O to refill its oxygen vacancies leaving hydrogen and/or carbon monoxide or syngas as intermediate product [8]. The intermediate product can then be used in a downstream fuel synthesis.

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Integrating redox reactors into a downstream fuel production process poses several design and operation challenges, including:

- Strong dependency on DNI results in fluctuating primary energy availability
- High operating temperatures of the redox reactor and different temperature levels within the production system cause high heat losses
- The aim for an energetically autonomous, grid-independent operation increases the need for a resilient and flexible process configuration
- Combining intermittent redox cycles with continuous downstream fuel synthesis leads to a temporal imbalance in mass flow on an hourly and seasonal basis

To solve some of those challenges, different process configurations have been selected in literature [9], [10], [11]. However, addressing those challenges systematically from a techno-economic perspective requires a co-optimization of design and operation of such systems. Design optimization determines the selection and sizing of adequate process integrators such as buffer storages and heat integration concepts and their link to core components: solar tower, CO₂ supply unit, redox reactor and fuel synthesis. An optimized operation strategy increases the system flexibility and continuous production under certain conditions. Within the PhD project, this analysis will be performed using a modular, object-oriented system model with grey and black box representations of the system components. The component models are linked through material and energy flows and the optimization decisions are formulated as a mixed-integer linear program, evaluated over a representative year of operation under fluctuating direct normal irradiance (DNI). The optimization simultaneously determines discrete design choices, such as the inclusion of thermal, electrical or intermediate-product storage, continuous capacity-sizing variables for the selected components, and time-dependent operating decisions, including storage charging/discharging or mass and heat flow routing.

The objective will be to minimize levelized fuel costs subject to requirements for operational flexibility and production continuity, while quantifying component utilization and heat recovery.

The analysis will identify how a structured selection, sizing and dispatch of the integration components affects the ability of solar-thermochemical pathways to deliver continuous fuel production and determines the technical and economic conditions under which they can compete with alternative low-emission fuel routes.

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Tail gas recirculation for fuel production via solar thermochemical redox cycles

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Solar thermochemical redox cycles are a promising alternative to the power-to-liquid (PtL) pathway for producing renewable synthetic fuels like sustainable aviation fuels (SAF) [1]. A metal oxide (e.g. Ceria) is heated to temperatures of around 1500°C using concentrated solar irradiation and reduced at low partial oxygen pressures creating oxygen vacancies in the lattice, described by the reduction extent δ . The reduced metal oxide can then react at temperatures of around 800°C with H₂O and CO₂, producing a mixture of H₂ and CO, called syngas and oxidizing the metal oxide, completing the cycle (Fig.1). The syngas is then used to produce hydrocarbons (mostly alkanes) of different carbon-chain-lengths via Fischer-Tropsch-Synthesis (FTS). Short chained hydrocarbons like CH₄, C₂H₆, C₃H₈ and C₄H₁₀ cannot be directly used as SAF, as they remain gaseous in most conditions. Therefore, these tail gases should be recycled back to syngas to improve the output of desired product and the overall system efficiency. In a redox cycle, tail gases could be used to help reduce the metal oxide to higher reduction extents δ than with pure thermal reduction, even at temperatures below 1000°C [2], producing syngas or CO₂ and H₂O (partial/complete oxidation, Fig. 2).

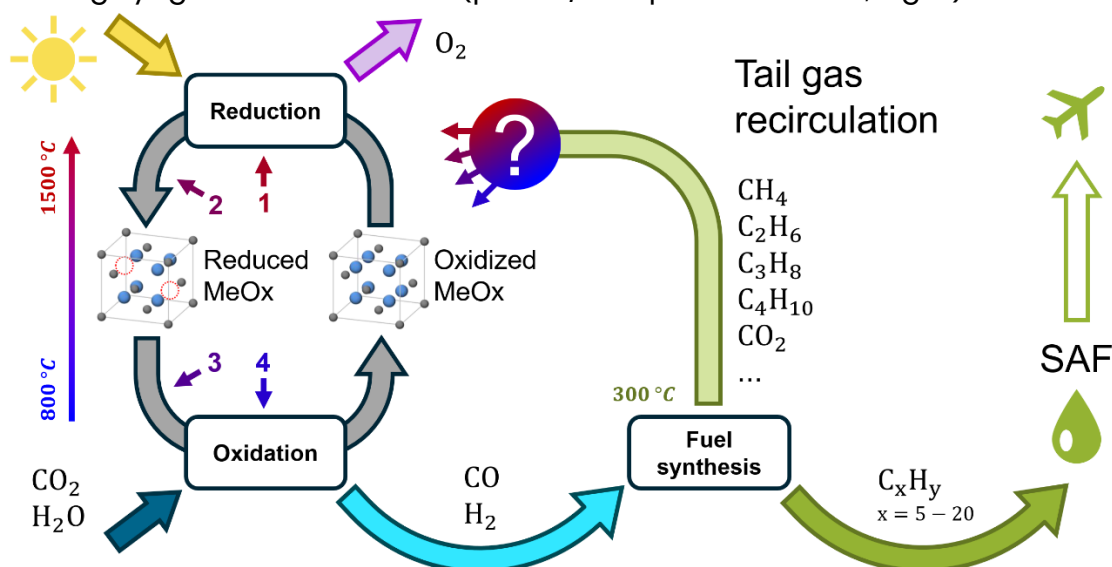


Fig.1: Schematic of solar thermochemical redox cycle with downstream fuel synthesis.

As depicted in Fig. 1, the periodic nature of solar thermochemical redox cycles leaves multiple options for when this tail gas assisted reduction should be carried out. For example, tail gases could be introduced during the reduction step, resulting in a combined thermal and tail gas assisted reduction, possibly reducing the peak reduction temperature (option 1) or after the thermal reduction, increasing the

reduction extent (option 2). Alternatively, the tail gas reduction could be carried out at lower temperatures before (option 3) or even during the oxidation step (option 4). This way the necessary heat for tail gas assisted reduction can be provided by the sensible heat stored in the metal oxide or by the heat produced by the oxidation reaction. Additionally, as can be seen in Fig.2, partial oxidation of the tail gas is dominant at temperatures between 800°C and 1000°C, therefore directly producing syngas.

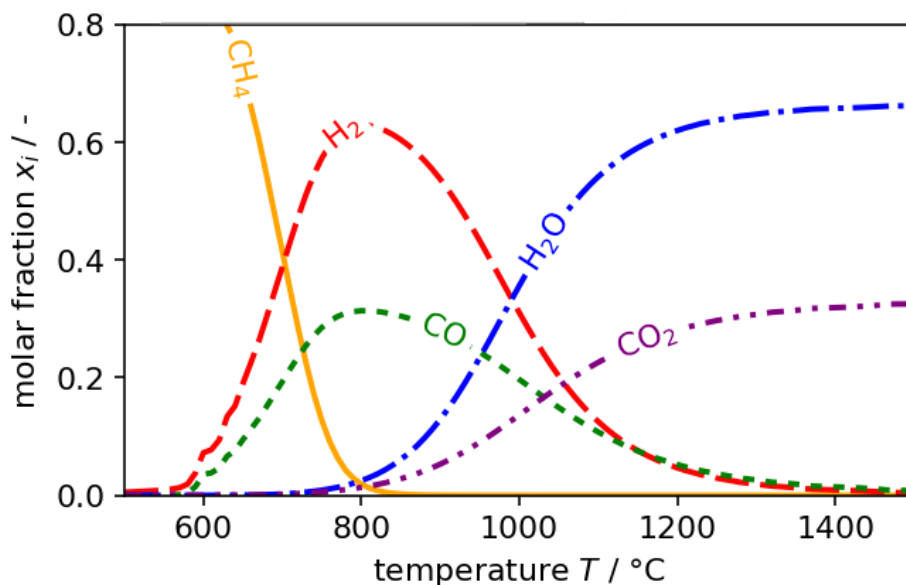


Fig.2: Equilibrium product composition of methane with ceria at a reduction extent of $\delta=0.05$.

In this work the different options described for integrating tail gas recirculation into solar thermal redox cycles and its effects are analyzed. Equilibrium product compositions of tail gas assisted reduction and oxidation and the resulting temperatures and reduction extents are modelled for the different options. To take into account the shape of the reduction extent, which can result in improved conversions to syngas and higher efficiencies, 1D transient simulations of the metal oxide along its depth are carried out. Finally, the system efficiencies are approximated for each option to provide a good basis for comparison. Additionally, the effects of different amounts and compositions of the tail gas are studied.

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Parametrized Thermomechanical Modelling of Ceramic Redox Geometries under Transient Heating for Thermochemical Fuel Production

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Ceramic redox materials are key enablers for thermochemical fuel production, particularly in cyclic water and carbon dioxide splitting processes, where high-temperature redox reactions are driven by controlled thermal transients [1,2]. In such applications, the materials are exposed not only to demanding chemical conditions but also to repeated heating and cooling cycles that can induce steep internal temperature gradients. For brittle ceramics, these gradients are of particular importance because failure is typically governed by tensile principal stress [3,4]. Consequently, the mechanical stability of redox structures is strongly affected by geometry, thermal loading, and the resulting spatial and temporal distribution of temperature inside the specimen. While the thermochemical functionality of redox materials has been widely studied, the fracture-relevant thermomechanical response of different specimen geometries under process-like transient heating conditions is less systematically resolved.

The present work addresses this gap by performing a first thermomechanical screening of representative parametrized ceramic redox specimen geometries under transient heating and cooling. To this end, a numerical model is developed, which is subsequently validated using corresponding specimen geometries heated in an IR furnace. The numerical model is reduced to the specimen itself to detect the influence of geometry and thermal loading history on internal temperature gradients and stress development. Heat transfer is modelled by transient conduction inside the ceramic structure, while the surface is heated by thermal radiation and convection from a time-dependent furnace environment. The furnace temperature is prescribed as a function of time in order to represent controlled heating and cooling ramps as well as optional dwell periods. The resulting temperature field is then transferred to a structural analysis in which thermally induced stresses are evaluated. The main outputs of the simulation are the resulting maximum principal tensile stress, $\sigma_{1,max}$ as a function of time, the internal temperature difference within the specimen and the first time instant at which the tensile stress limit is exceeded. These quantities are used to assess how different specimen geometries respond to varying heating and cooling rates and how quickly a given geometry reaches a critical tensile stress level.

In this way, the study aims to identify which specimen variants are more susceptible to thermally induced cracking during process-relevant thermal cycles. The

approach provides a first screening for the mechanical robustness of ceramic redox structures under radiative heating conditions relevant to thermochemical fuel production.

An exemplary, representative internal temperature difference and stress distribution for a cylindrical body is shown in Fig. 1, illustrating the location of the maximum tensile stress during the heating cycle with a heating rate of 100 K/min after 895 seconds.

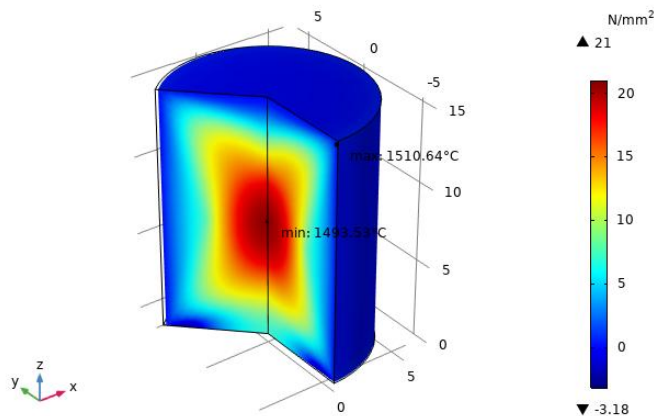


Fig.1: Distribution of thermally induced tensile stress while heating a cylindric specimen with 100K/min

During the experimental validation, a temperature profile is set and the occurrence of cracks is used to assess whether critical stress levels have been exceeded. The ability to relate furnace ramp conditions directly to fracture-relevant stresses is of practical importance for both material screening and process design. In future work, the thermomechanical approach will be extended by additional process conditions such as reduction extent, enabling a more comprehensive multi-criteria assessment of the interplay between thermal loading, mechanical stability, and redox performance.

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Electrically assisted thermochemical redox processes for thermal energy storage with doped perovskite metal oxides

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The decarbonization of high-temperature industrial processes—ranging from 773 to 2273 K—remains one of the most pressing challenges in the energy transition, as sectors such as steel, cement and chemicals continue to rely heavily on fossil fuel combustion. The rapid expansion of variable renewable energy sources has led to increased instances of energy curtailment and even negative electricity prices in European markets, creating a strong incentive for flexible, high-temperature solutions that can utilize surplus power and provide heat on demand.

Electrically heated thermal energy storage (E-TES) offers a promising route by converting excess renewable electricity into high-temperature heat, which is stored and released on demand. Unlike conventional heating elements made of metals or SiC, direct resistive heating of the storage material itself minimizes interfacial losses and enhances thermal homogeneity. While standard thermal storage relies on a heat transfer fluid (HTF) for both charging and discharging, joule-heated systems allow for HTF-free charging while the HTF remains necessary for efficient heat extraction during discharge. Heat is generated in situ via electrical resistance when a current passes through the storage module. Joule heating has emerged as a fast, efficient, and adaptable solution for in-situ heat generation in functional materials and reactor designs [1]. This strategy enables both grid flexibility and the electrification of industrial heat, potentially offering a scalable solution to the dual challenges of renewable intermittency and high-temperature thermal demand.

Non-stoichiometric perovskite oxides ($\text{ABO}_{3-\delta}$) are particularly attractive for E-TES due to their high thermal stability and reversible oxygen-vacancy-based redox behavior; thus they can be used for both sensible and thermochemical energy storage [2]. Among the most studied families are manganates (e.g., CaMnO_3) and ferrates (e.g., SrFeO_3), which exhibit well-established oxygen non-stoichiometry, promising defect-mediated transport properties and robust redox cycling within the 573–1373 K range [3]. These qualities make them strong candidates for integrated heat storage and delivery. In combination with Joule heating, electrically heated nonstoichiometric perovskite oxides act simultaneously as resistive heaters and redox-active storage media.

In this context, doped variants of CaMnO_3 and SrFeO_3 are evaluated for their combined redox activity and electrical performance. Density functional theory and Boltzmann transport modeling are coupled with solid-state synthesis and characterization of redox properties and electrical conductivity to derive design

rules for optimal performance [4]. Based on this, an extensive experimental study is carried out to evaluate the influence of doping on electrical conductivity and identify the most promising doped compositions. In the next step, a small-scale test setup is designed and constructed to demonstrate a proof-of-concept of joule-heated perovskites for thermal energy storage via electrically assisted thermochemical redox processes.

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Investigation of catalyst anodic structures for SO₂ Depolarised Electrolysis for Hydrogen Production

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Hydrogen produced by water electrolysis, even when powered by renewable electricity, still remains costlier compared to fossil fuel derived hydrogen, with the main driver being the electricity costs of the electrolysis. Hence, the energy cost is set by the cell voltage, and dominated by the sluggish, thermodynamically demanding oxygen evolution reaction (OER) at the anode. The Hybrid Sulfur (HyS, Westinghouse) cycle circumvents this bottleneck by replacing the OER with the anodic oxidation of sulfur dioxide. In its electrochemical step, the SO₂-depolarized electrolysis (SDE), SO₂ is oxidized to sulfuric acid while hydrogen evolves at the cathode (Figure 1). Beyond its original role within the thermochemical HyS loop, SDE is emerging as a standalone technology [1].

SDE not only lowers the energy demands compared to conventional water electrolysis (0.158 V vs 1.23 V minimum thermodynamic voltage), but also yields two valuable products, hydrogen and sulfuric acid. The whole process relies on the Sulfur Oxidation Reaction (SOR) as the anodic reaction (0.158 V vs. RHE) [2].

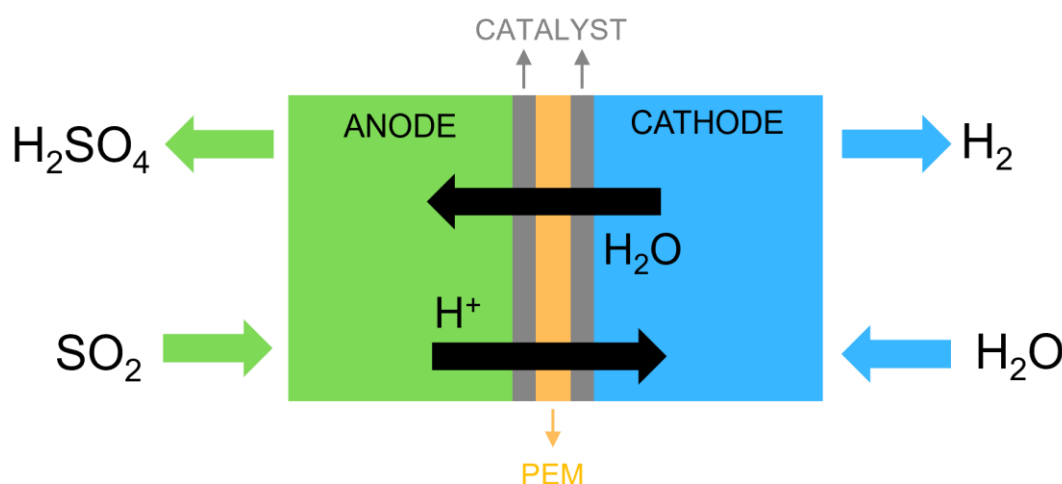


Fig.1: Basic sketch of a SO₂-depolarized Electrolyser setup

SO₂ can be derived from the solar-driven HyS cycle. However, if SDE is used as a standalone technology, SO₂ can be also sourced from various industrial operations, including mining, fertilizer production, sulphur combustion and other processes in which SO₂ is emitted [3]. The utilization of these industrial

emissions, enables the mitigation of SO_2 pollution, by generating sulfuric acid as useful by-product.

To increase viability of the SDE process, it is necessary to achieve low operating voltages and high current rates. A substantial challenge is the optimization of anode oxidation reaction of sulfur dioxide which is the kinetic bottleneck of the process. To address this challenge, this work explores the implementation of a three-dimensional catalyst architecture at the anode. The study focuses on optimizing both the catalyst ink composition and the coating process. The catalyst-loaded substrates are characterized electrochemically using (i) a three-electrode electrochemical cell and (ii) a single cell full SDE setup. Linear Sweep Voltammetry (LSV) and Chronoamperometry (CA) are carried out to quantify activity and long-term stability. Overall, we find that microporous electrodes exhibit enhanced current densities relative to their planar analogues due to optimized mass transport of the SO_2 reactant and the electrolyser configuration offers an additional knob to further boost cell performance.

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Structured Iron Oxide-Based Catalysts for Solar-Driven Sulphur Trioxide Splitting in Sulphur-based Thermochemical Energy Storage Cycles

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Concentrated solar thermal energy can drive high-temperature thermochemical cycles that can either produce or store energy carriers, without relying on the use of fossil resources. This work investigates a three-step thermochemical concept for direct solar energy storage in the form of elemental sulphur, a chemically stable and transportable energy carrier [1,2]. The cycle can be integrated with concentrated solar thermal systems, enabling solar energy to be stored in the chemical bonds of elemental sulphur. The stored energy can be recovered on demand, through sulphur combustion, providing dispatchable high value heat and/or electricity independently of solar availability. Within this concept, the present work focuses on the high-temperature, catalytic SO_3 decomposition step and the development of structured catalysts suitable for solar receiver-reactors. The endothermic decomposition of sulphur trioxide (SO_3) into sulphur dioxide (SO_2) and oxygen is a common and rate-limiting step in the cycles and it is typically carried out at 800–900°C. This reaction has traditionally relied on platinum-based catalysts, whose high cost and limited availability motivate the search for cheaper and more abundant alternatives. Iron oxide (Fe_2O_3) based catalysts have emerged as promising candidates, combining reasonable catalytic activity with low cost, wide availability, and good thermal stability. This work presents the ongoing development of Fe_2O_3 -based catalysts for solar-driven SO_3 decomposition, following a progression from powder catalysts to structured ceramic materials suitable for integration into solar receiver-reactors. In the first stage, iron oxide powders –pure and supported aluminosilicate carriers– were synthesised by dry mixing (DM) and Dissolution–Evaporation–Precipitation (DEP) routes, shaped into near-spherical particles (1–2 mm) (Figure 1, b) and evaluated catalytically in a laboratory-scale fixed-bed reactor [3] (Figure 1, a) to determine SO_3 conversion. The catalytic evaluation was carried out at 850°C using concentrated liquid H_2SO_4 (~97 wt%) as feedstock. Iron oxide-based materials exhibited good catalytic activity, achieving SO_3 conversion rates up to ~50% of the corresponding thermodynamic equilibrium value, while no loss of activity was documented after at least 1 h of on-stream operation. The performance was enhanced upon structuring the material into porous granules, indicating a clear correlation between activity and structural form. Physicochemical characterisation both before and after stream exposure, including XRD, SEM, EDS, BET and mercury intrusion, was used to correlate catalyst

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structure and composition with catalytic performance. In the second stage, the most promising formulations were further structured into porous bodies (i.e., extruded in monolithic honeycombs Figure 1, c), which are better suited than packed powder beds for direct or indirect solar irradiation, offering lower pressure drop, improved gas-solid contact, and enhanced mechanical robustness under realistic operational conditions. Overall, the combination of catalytic activity, mechanical robustness and cost-effectiveness reinforces the potential of the Fe-based materials for application in solar thermochemical energy storage systems, withstanding the harsh conditions associated with the sulphuric acid cycle.

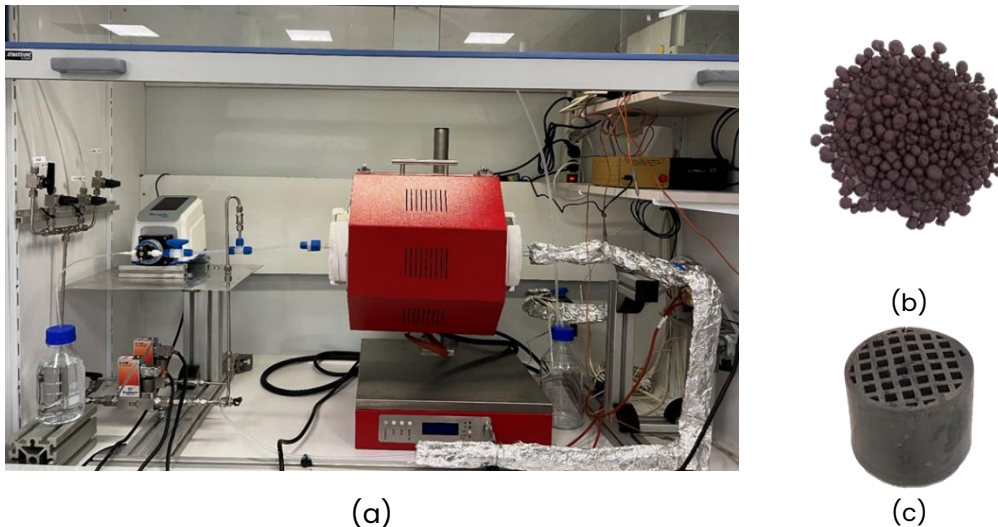


Fig.1: (a) Catalytic evaluation unit at CERTH, (b) Fe_2O_3 near-spherical granules (1000°C), (c) Fe_2O_3 extruded honeycomb (950°C)

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Acknowledgements

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Clay Calcination with Renewable Energy

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The global cement industry accounts for roughly 8 % of worldwide anthropogenic CO₂ emissions [1], is essentially unavoidable [2] and projected to keep rising, particularly in developing regions. In conventional cement clinker production, roughly two-thirds of associated emissions are process CO₂ released by the chemical decomposition of limestone – inherent to the chemistry itself, and thus impossible to eliminate through efficiency gains or fuel switching; at best, it can only be captured after the fact. Clay calcination offers a compelling alternative. Used in blended cements such as LC3, calcined clay can substitute a large share of clinker, releasing water vapor instead of CO₂ in its production and avoiding such process emissions entirely. In addition, it requires a maximum temperature of not more than 900 °C, while conventional clinker production requires 1450 °C, making clay calcination well-suited for renewable or electrified heat sources such as concentrated solar or electric calciners. Coupling clay calcination with renewable energy thus offers a scalable route to decarbonizing cement while meeting rising global demand. [3]

Several electrified heating routes are being explored for clay calcination. Microwave-based heating generates heat directly within clay particles, avoiding conventional heat transfer, but clay's weak dielectric absorption keeps specific energy consumption at least as high as resistive methods; combined with the high cost of magnetrons needed for megawatt-scale generation, this route appears comparatively less promising. [4] Plasma technology produces flame temperatures far exceeding what clay calcination requires, and these are not merely unnecessary but actively detrimental, since cement binding capacity degrades above ~900 °C, meaning the plasma flame would need to be diluted with accompanying gas to be usable at all. Combined with significant electrode wear and lower electrical efficiency, plasma carries comparatively many disadvantages relative to its benefits for clay calcination. [5] Resistive heating, the industrial standard for electric heating, offers a high base efficiency and relatively long lives for high temperature heating elements made from MoSi₂ or SiC. Heat can be transferred to a conveyed material bed via radiation and convection, or heaters can preheat gas for flash or fluidized-bed calciners. Resistive elements directly embedded in fluidized beds or in moving packed beds are also suitable options. [6, 7, 8] Inductive heating requires higher capital investment in power electronics and, since clay itself is non-conductive, relies on conductive or ferromagnetic susceptor materials to couple with the magnetic field. While specific energy consumption is typically higher than for resistive heating, efficient coupling can minimize these losses to within just a few percentage points of resistive systems, and induction

offers potential advantages including longer heater lifetimes and higher power density per heating volume. [9] Direct solar calcination in a concentrating tower system is also possible and may offer favorable overall economic costs [10].

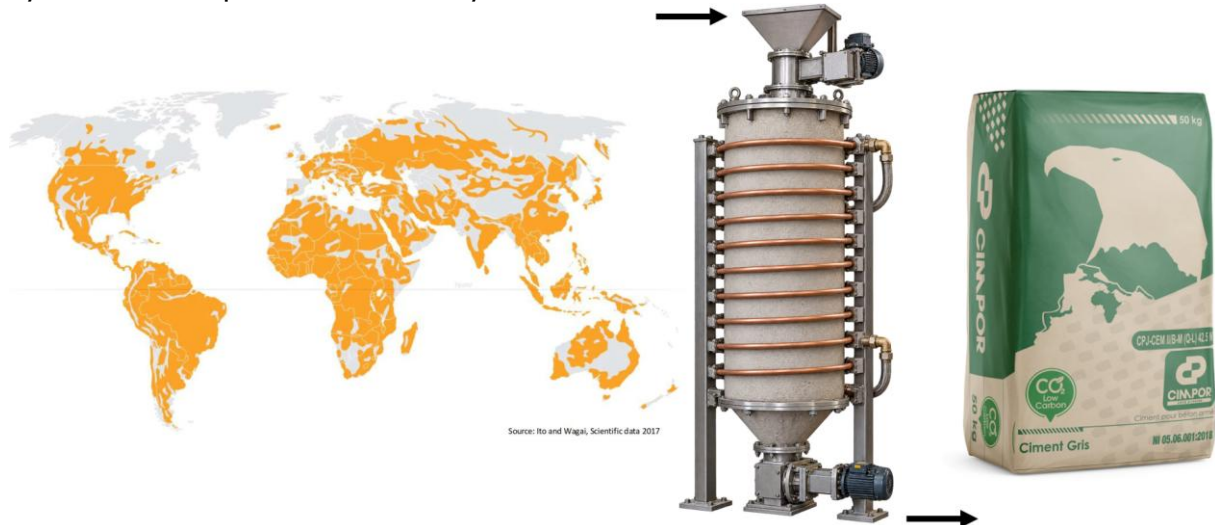


Fig.1: Left: global availability of Kaolinitic Clays [Ito and Wagai, Scientific Data 2017]; middle: Electric Clay Calciner imagination [generated with ChatGPT]; right: commercial LC3-cement [cimpor-website].

This presentation introduces a novel electric clay calcination heating concept optimized for heating efficiency, system lifetime and economic costs which is imagined in Fig. 1.

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Temperature Control in Ammonia Synthesis Reactors Using Silicone Oil-Based Heat Transfer Fluids

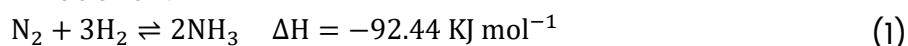
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Ammonia is one of the most important chemicals worldwide, with an annual production capacity of approximately 200 million metric tons and continued growth in demand [1]. Industrial ammonia production is dominated by the Haber-Bosch (HB) process, where nitrogen and hydrogen react over a catalyst in an exothermic equilibrium reaction:



Typically operated at 400–500 °C and pressures above 100 bar [2], the process relies almost entirely on fossil-derived hydrogen, accounting for approximately 1–3% of global CO₂ emissions [3]. Replacing fossil-derived hydrogen with hydrogen from water electrolysis can nearly eliminate all direct process CO₂ emissions. [4]. However, the inherent variability of renewable power generation leads to fluctuant reactant supply. Conventional HB synthesis plants are optimized for steady-state operation and tolerate only limited load (i.e. feed) fluctuations. The autothermal reactors used for this, in particular, depend on reaction heat to preheat the feed gas. Abrupt flow changes can destabilize the thermal balance, leading to unstable operation points or, in the worst case, extinguishing the synthesis reaction.

To address this limitation, this study investigates a thermally controlled reactor concept designed to enhance the operational flexibility of Haber-Bosch ammonia synthesis. Unlike conventional autothermal designs, the proposed multitubular fixed-bed reactor features an external heat transfer circuit that decouples temperature control from the exothermic reaction. While the synthesis gas mixture flows through catalyst packed tubes, a silicone-oil heat transfer fluid (HTF) circulates on the shell side, enabling active heat removal during periods of high conversion and external heat supply during low-load or intermittent operation. Figure 1 illustrates the reactor concept and its integration into a power-to-ammonia process.

Effective heat removal is essential during steady-state operation to increase per-pass reactant conversion. The thermal energy absorbed by the HTF can be recovered via an HTF heat exchanger or integrated in downstream processes. Conversely, during startup phases or reduced reactant supply, the reactor can be externally heated using the HTF heater. This external temperature control ensures operational stability and prevents the risk of reaction extinction.

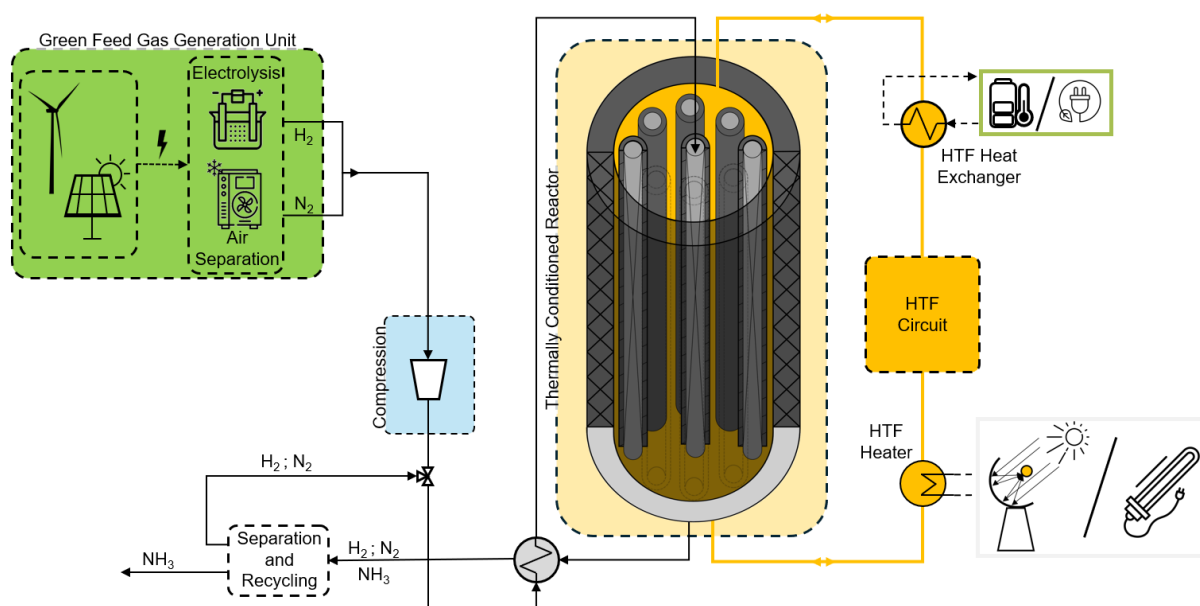


Figure 1: Design of a power-to-ammonia process utilizing a synthesis reactor thermally conditioned by a silicone oil HTF

The primary objective of this PhD study is to investigate the thermally controlled reactor concept for the HB ammonia synthesis. The research focusses on analyzing the reactor's thermal behavior, achievable per-pass reactant conversion, and integration efficiency relative to a state-of-the-art autothermal configuration.

Preliminary investigations utilize an industrial scale one-dimensional model to assess operational flexibility. A parametric study has been conducted over a load range of 25% to 225% (relative to a nominal load) examining the impact of feed gas inlet temperature, HTF inlet temperature, HTF mass flow and HTF flow direction on the single-pass conversion.

Future work will extend these findings to comprehensive process simulations. In parallel, a three-dimensional reactor model is being developed to localize hot spots, particularly at the tube/HTF interface. The resulting computational models will be validated using experimental data from a pilot scale setup.

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Solar-assisted Hydrothermal Liquefaction of microalgae and oleaginous yeast for the production of sustainable biofuels

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The steadily increasing global energy demand, coupled with the depletion of fossil fuel reserves, poses a major challenge to modern energy policy. Addressing this challenge requires the adoption of sustainable energy systems that reduce reliance on fossil fuels while mitigating greenhouse gas emissions [1,2]. Among biomass conversion technologies, Hydrothermal Liquefaction (HTL) has emerged as a promising thermochemical method for biofuel production due to its ability to directly process wet biomass, eliminating the energy-intensive drying step and improving overall process efficiency. HTL converts biomass into biocrude oil and other valuable by-products in the presence of water under subcritical or supercritical conditions, typically at temperatures of 250–550 °C and pressures of 50–250 bar [3,4]. The primary product, biocrude oil, can be further upgraded to produce fuels with properties comparable to conventional petroleum-derived fuels, while the process also generates an aqueous phase, a gaseous phase, and a carbon-rich solid residue (biochar) [3].

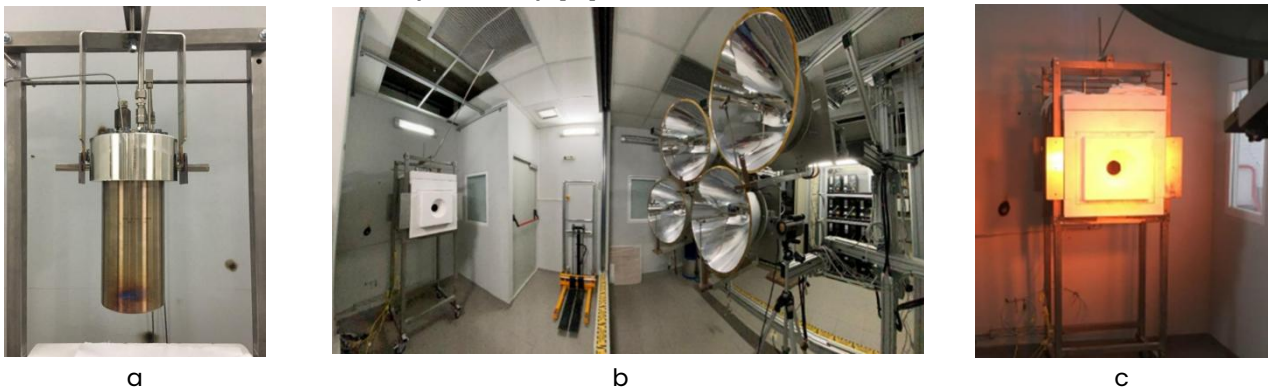


Fig.1: a. The autoclave batch reactor, b. HTL reactor and in-house solar simulator setup, c. HTL reactor during operation in the solar simulator

Despite its considerable potential, one of the main limitations of HTL is the high energy demand required to achieve and maintain the elevated temperatures and pressures necessary for the process. Integrating HTL with Concentrated Solar Technologies (CST) to supply the required thermal energy offers a sustainable and energy-efficient alternative to conventional heating methods. This solar-assisted HTL approach can reduce operational costs and fossil fuel consumption while enhancing the overall sustainability of the process, contributing to the development of next-generation fuels [1].



Fig. 2: Preliminary design of a pilot-scale mobile HTL reactor with parabolic troughs

This study investigates the performance of a solar-assisted HTL process using microalgae [5] and high-lipid oleaginous yeasts as feedstocks in a laboratory-scale batch autoclave reactor (Fig. 1a). A series of experiments is carried out using both a conventionally heated batch autoclave reactor and CERTH's in-house solar simulator, comprising four Xenon arc lamps, to reproduce realistic operating conditions for a solar-driven HTL system (Fig. 1b) [4] and enable a direct comparison between conventional and solar-assisted HTL. The effects of a wide range of operating temperatures and retention times on the HTL process will be systematically evaluated. The experimental findings are expected to identify the optimum operating conditions for maximizing biocrude yield and support the design, development, and optimization of a pilot-scale mobile solar-assisted HTL reactor (Fig. 2). The resulting products will be characterized using physicochemical analyses, including bomb calorimetry, elemental analysis, and gas chromatography, to assess their composition and fuel properties.

ACKNOWLEDGEMENT

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Integration of Thermal Storage in a Packed Bed using waste materials for Power-to-Heat applications in Mediterranean industries

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The Mediterranean region is particularly vulnerable to climate change, with temperatures rising by approximately 20 per cent above the global average, placing increasing pressure on resources, economies and energy systems [1]. Decarbonizing the industrial sector in the Mediterranean region requires solutions capable of reducing dependence on fossil fuels in medium- and high-temperature thermal processes [2]. In this context, the integration of low-cost thermal storage with Power-to-Heat schemes presents itself a promising alternative for harnessing surplus renewable energy and supplying process heat at around 300 °C. This research, conducted as part of the European GREENOLIVE project, addresses the design, optimization, and evaluation of a packed-bed thermal storage system with oil and local waste materials as filler. When coupled with a 600 kWe photovoltaic plant, the proposed system is expected to supply 18-20% of the thermal demand of a polystyrene manufacturing process (main process temperature: 300°C) in an industrial facility in Turkey, as shown in Figure 1.

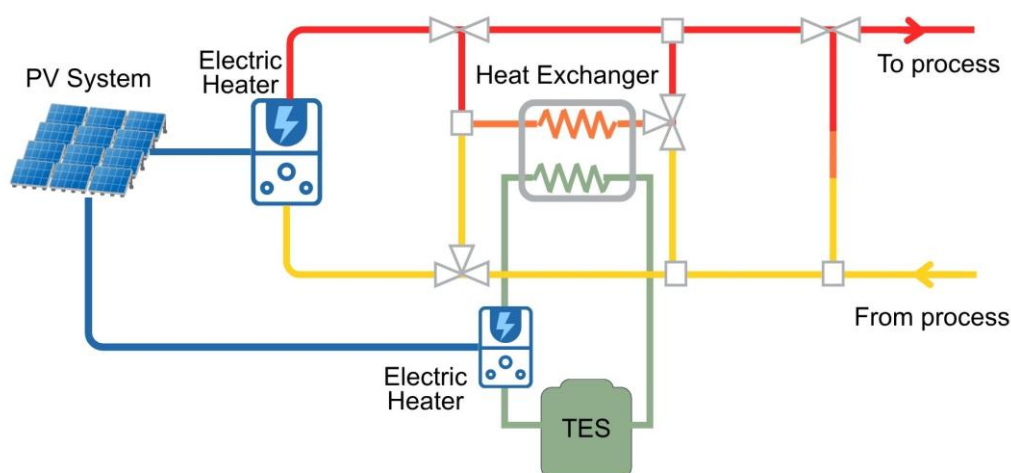


Fig.1: Overview of the GREENOLIVE Power-to-Heat **System** with Thermal Storage.

The study adopts a theoretical-experimental approach that includes a review of the state of the art, thermophysical properties characterization of filler materials and heat transfer fluid, the analysis of site data on thermal demand and solar PV availability, and the improvement of a thermohydraulic simulation model for packed-bed tanks. In addition, experimental tests will be conducted on

representative configurations to validate the model and optimize the system's geometric and operational design.

The proposed solution is expected to reduce natural gas dependence, lower energy costs, and increase the flexibility of heat supply using local resources and solar energy. Ultimately, this study advances sustainable energy integration within industrial contexts, supporting climate change mitigation strategies across the Mediterranean region.

Acknowledgements

This research is being carried out within the framework of the GREENOLIVE project (Project ID: GREENOLIVE A_T_2.1_0213), funded under the Interreg NEXT MED Programme and co-funded by the European Union.

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Assessment of electrified metallic PCM storage system strategies under different orientations

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1. Introduction

Conventional high-temperature PCMs, such as inorganic salts, inherent a low thermal conductivity which causes a slow heat transfer rate. In contrast, Metallic PCMs offer many advantages such as thermal stability, high thermal conductivity, and a faster heat transfer rate compared to conventional PCMs [1]. Integrating power-to-heat concepts, such as electrified metallic PCM latent energy storage, is an innovative way to advance industrial decarbonisation and improve charging efficiency [2]. The present study is proposed to investigate the effect of system orientation (horizontal and vertical) on the performance of a thermal energy storage system using a metallic PCM under external electrification heating strategy. The main objective is to identify the optimal orientation that provides the highest thermal efficiency, the shortest melting time, and the most uniform temperature distribution, thus contributing to the development of more efficient and practical thermal storage systems for industrial applications.

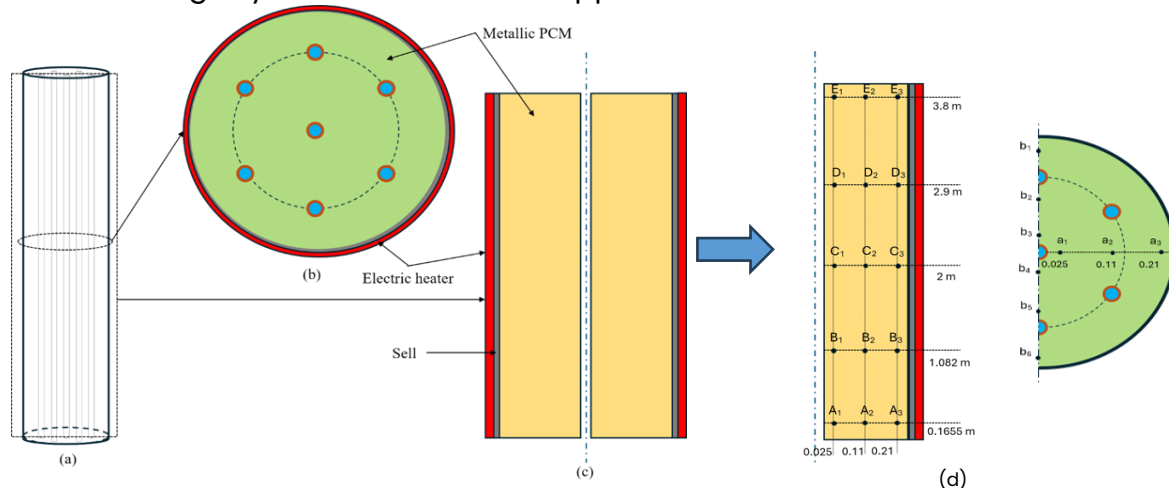


Fig 1: Schematic diagram of the (a) shell-and-multitube metallic PCM with (b) cross-section, (c) longitudinal-section and (d) measurement points distribution.

2. Description of Model

A shell and multitube latent thermal storage system filled with a metallic PCM was developed to assess the influence of vertical and horizontal storage orientations on thermal performance. The system consists of an outer cylindrical shell made of stainless steel, 4 m high, 0.56 m in diameter, and 0.007 m thick. It contains seven stainless steel tubes with an outer diameter of 0.023 m and are arranged as shown in Fig. 1. The Zinc-aluminium alloy (ZnAl6) was chosen as phase change material (PCM). A three-dimensional numerical simulation model was developed using ANSYS Fluent. Pressure-velocity coupling uses the Pressure-Linked Equations (SIMPLE) Method for metallic PCM domain. The pressure term is corrected using the

PRESTO! scheme, and the spatial discretization schemes of the momentum and energy expressions are second-order upwind.

3. Results

From fig. 2, It be clear that the metallic PCM is initially in a solid state and after the heat supply to external wall by electric heater, the heat passing through the wall materials then it is transferred to the annular region where the metallic PCM is located. The temperature of the PCM gradually increases in both configurations. By this time 60 minutes, the main heat transfer mechanism is conduction. After the temperature in the PCM region reaches the phase transition temperature of 381°C , the PCM begins to transform from solid to liquid and a thin layer of liquid PCM is formed near the heated wall. Since the density of the liquid PCM decreases with increasing temperature, natural convection is generated driven by buoyancy, and then natural convection is the main heat transfer mechanism. As time progressed, the melted PCM in the upper region of the vertical storage exceeds the limited temperature (500°C) around 150 minutes, while the large volume of PCM stills in the solid state in the bottom region as shown in Fig.3. During this stage, weak natural convection can be observed, and heat transfer depends on conduction mode, and this reduces the heat transfer rate in vertical storage configuration. In contract, the horizontal configuration reached to full melting while the temperature still under the limited temperature.

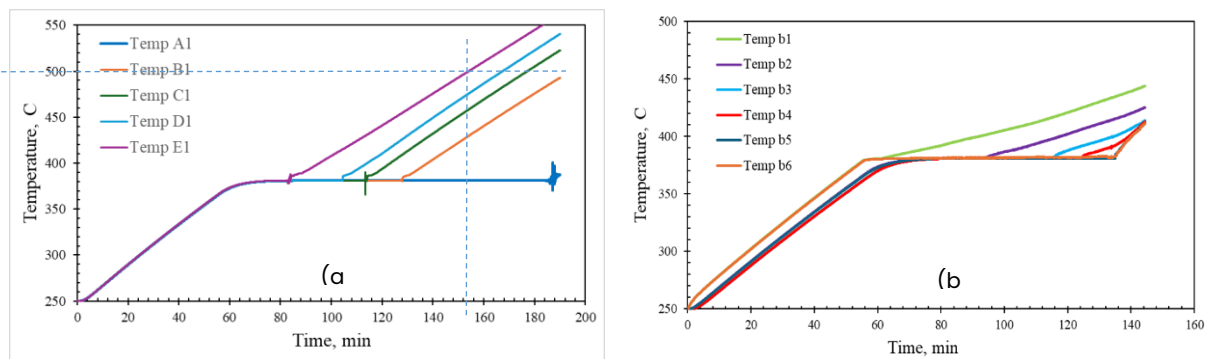


Fig2: Temperature recorded at different measuring points in axial direction for (a) horizontal and (b) for horizontal during electrification process.

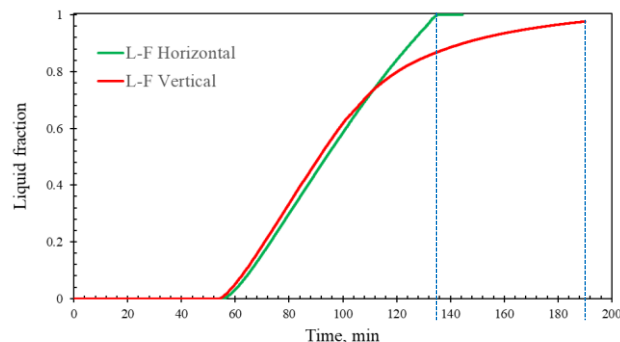


Fig 3: evaluation liquid fraction over time during electrification process for both configurations.

Acknowledgement

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Annual Assessment of a novel Integrated System Combining Photovoltaics, Compressed Air Energy Storage, Reverse Osmosis and Concentrated Solar Power

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Reverse osmosis (RO)-based desalination is considered the most promising solution to mitigate water scarcity, a challenge currently affecting over one-third of the global population. However, the main drawback of this technology lies in its high energy demand that is currently provided mainly by fossil fuels. To ensure sustainable development, the integration of renewable energy sources is essential. The Spanish national project SOLDESALBIO and the European project ASTERIX-CAESAR propose a comprehensive scheme that combine RO-based desalination with Photovoltaics (PV), Compressed Air Energy Storage (CAES), Thermal Energy Storage (TES) and high-temperature CSP, which aims the combined freshwater and electricity production with high share of renewable energies. This work presents an annual simulation of the proposed scheme, considering four operating scenarios that combines the operation with and without combustor and the use of a single compressor or two smaller ones in parallel.

In the scheme proposed, the RO plant is integrated into a solar minitower Concentrating Solar Power (CSP) and PV Plants (abbreviated as Solar Power (SP)), complemented by TES and CAES systems [1]. The operation strategy of the system is proposed as follows: during daytime hours, PV is mainly used to charge the CAES system through air compression and the TES by driving air through the CSP plant, while surplus energy is allocated to both RO operation and grid export. Stored compressed air is subsequently expanded to drive the RO unit after sunset via a pressurized air-liquid (GL/P) system, and to support CSP power generation during the evening peak, when electricity prices are highest, using a pressurized air-based Brayton cycle [2]. A combustor is included to maintain the air inlet turbine temperature at nominal conditions.

Fig.1 shows a diagram of the system configuration and the main results of the annual simulation are presented at Table.1.

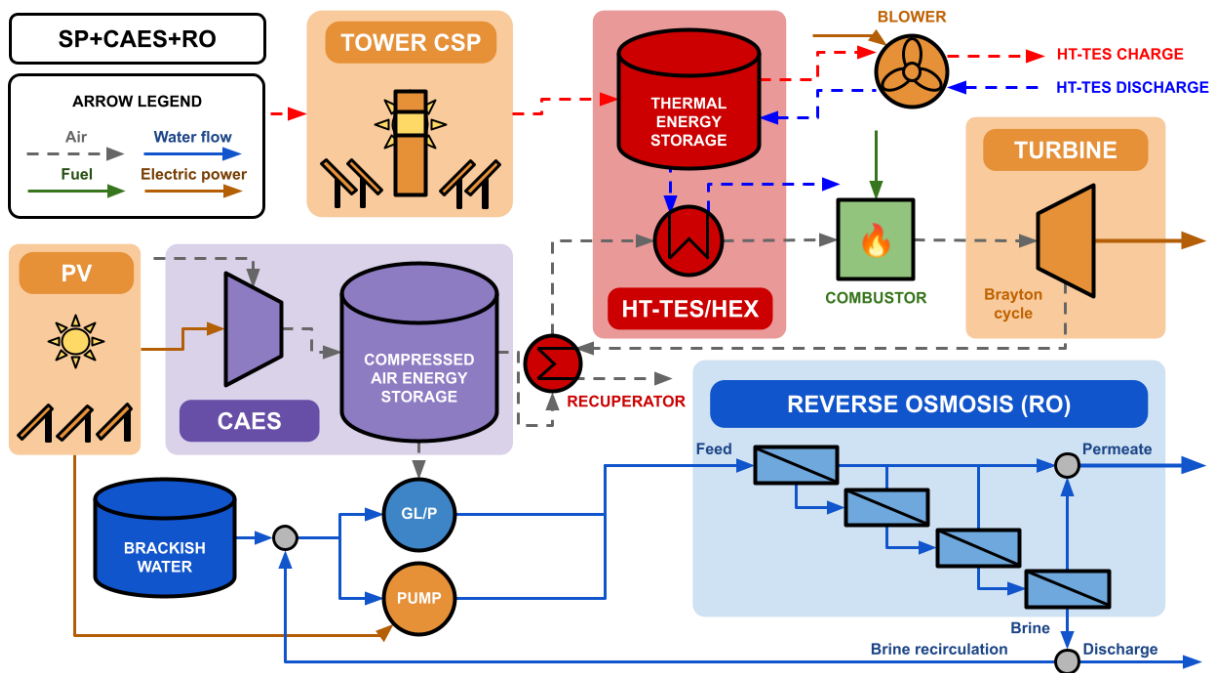


Fig.1: Diagram of the SP-CAES-RO hybrid system.

Operating scenario	Freshwater	Net energy	Combustor
Without combustor and a single	34,019 [m ³]	1,083 [kWh]	0.00 [ton]
Without combustor and two	37,260 [m ³]	988 [kWh]	0.00 [ton]
With combustor and a single	33,093 [m ³]	1,085 [kWh]	7.53 [ton]
With combustor and two	37,032 [m ³]	954 [kWh]	9.10 [ton]

Table.1: Annual freshwater volume, net energy and the amount of fuel consumed by the combustor.

The results show that the use of two compressors increases the annual freshwater production from 34,019 to 37,260 [m³] without the use of combustor, due to improved CAES charging coverage. However, the single-compressor configuration provides higher net power generation, reaching approximately 1.08 MWh annually, mainly due to the higher PV power available for electricity production. The combustor has a limited impact on annual net power generation, while requiring 7.53–9.10 tonnes of fuel depending on the compressor configuration. Further economic analysis is required to assess the benefits of combustor operation, particularly considering its potential to increase turbine power dispatch during periods of higher electricity prices.

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Multiscale design of a modular hybrid PV–CST architecture

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The transition to sustainable energy systems requires innovative solar technologies capable of delivering reliable, efficient power generation. Hybrid solar concepts combining different conversion pathways offer promising opportunities to enhance overall system performance and flexibility. In this context, hybrid systems integrating photovoltaics (PV) and concentrated solar thermal (CST) technologies have recently emerged as a potential approach to improve solar energy utilization.

State-of-the-art crystalline Silicon PVs have an efficiency of about 24% in transforming solar energy into electricity. This is the dominant solar technology for several reasons. Among them, it produces electricity that can be easily converted into other forms of energy (heat, work, chemical potential, etc.), because it has become cheap after years of industrial refinement and because its modularity enables gradual, scalable, and customized deployment. In contrast, CST technologies achieve efficiencies of up to 90%, produce only heat, a less versatile energy carrier, and highly modular CST configurations remain relatively uncommon. Also, they are typically bulky (with a large collection area) and costly because they require precision-bent mirrors, thermally resistant materials, and effective insulating storage systems. A hybrid PV–CST requires all the expensive elements of the CST, plus PV cells, and always includes some extra component to integrate the two technologies. In this sense, for the hybrid to be competitive as an emerging technology, its additional efficiency relative to PV should more than offset the device's economic cost [1]. Additionally, a modular design would be more appealing for end users, potentially reaching a broader range of businesses and industries.

We propose to use spectral splitting to perform the hybridization; it is an implementation of a selective surface that spatially separates the frequencies that are better harvested by PV cells and directs them towards the cells, while concentrating the rest of the light onto an absorber surface. To collect efficiently, despite converting it into electricity or heat, one needs to maximize the power flux through the surface of the semiconductor or absorber. This flux is maximum when the light is incident normally on the surface. This is only possible if all the optical components (cells, selective surface, and absorber) move together, following the sun.

We propose a version of a Cassegrain collector, which is basically a two-stage version of a parabolic dish, in which a primary parabolic mirror first reflects

the light into a secondary hyperbolic mirror, which then reflects it, concentrating it into a spot. In our design, the primary mirror is semi-reflective, allowing the desired frequencies to be transmitted towards the cells placed behind it. This is shown in Figure 1, which presents a ray-tracing simulation of the device, with its corresponding geometry.

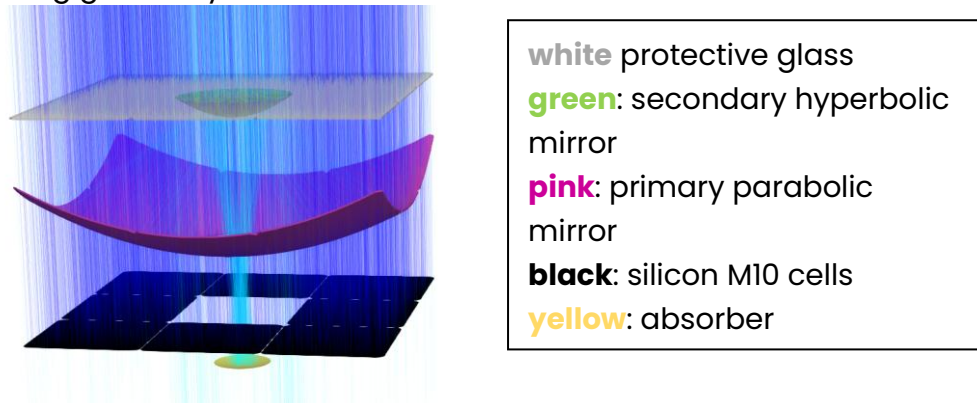


Fig.1: The proposed module and ray-tracing results

The design methodology was multi-scale. First, a comprehensive selection of sustainable optical materials was conducted (atomic scale), avoiding rare and scarce elements and toxic, expensive materials. Then, geometrical optics was addressed, using an open-source ray-tracing code: Meso-Star. (2026). Solstice, Version 0.9.1. The selective surface was optimized with Solpoc [2]. For the latter, an optimization criterion was developed that accounts for the angles of incidence on the curved surfaces and the spectral response of both the absorber and the cells. A thermal model for heat harvesting using circulating thermal oil is included, which allows to estimate the temperature and volume flux of the heat production.

Our preliminary results are that the total fraction of collected solar power is 44%: 12% as electricity (73.3W) and 32% as heat (195.5W), which would be constant throughout a clear day. So, we manage to come with a modular design that practically doubles the efficiency of silicon PVs, by complementing electricity with heat production. At this scale the module can be used for domestic purposes (14% of a person mean energy consumption in Europe), but also for low- and medium-temperatures industrial processes.

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Solar heat production using parabolic trough collectors

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The increasing demand for industrial process heat and the need to reduce fossil-fuel consumption have encouraged the integration of solar thermal technologies into industrial applications. Algeria possesses a particularly favorable solar resource, with high levels of direct normal irradiation (DNI), especially in the Saharan region, providing suitable conditions for concentrating solar thermal technologies [1]. Solar industrial process heat has significant potential for supplying low- and medium-temperature thermal requirements and reducing conventional fuel consumption [2]. Among concentrating technologies, parabolic trough collectors (PTCs) are a mature and promising option for industrial process heat applications [3]. This study investigates the potential of PTCs for supplying solar heat to a wool-washing process in Algeria. The proposed system (fig. 1) is designed to provide hot water for the washing process while reducing the contribution of a conventional auxiliary heating system. The annual thermal performance is simulated using Greenius, considering hourly solar irradiation, collector characteristics, operating temperature, solar-field configuration, thermal losses, and the process heat demand. greenius enables the assessment of concentrating solar thermal systems and process-heat applications through dynamic annual simulations [4]. Key performance indicators include annual useful solar heat production, solar-field efficiency, solar fraction, and auxiliary energy consumption. The study aims to demonstrate the technical feasibility of integrating PTC technology into wool-washing processes and to assess its potential contribution to reducing conventional energy consumption and associated carbon emissions in Algeria.

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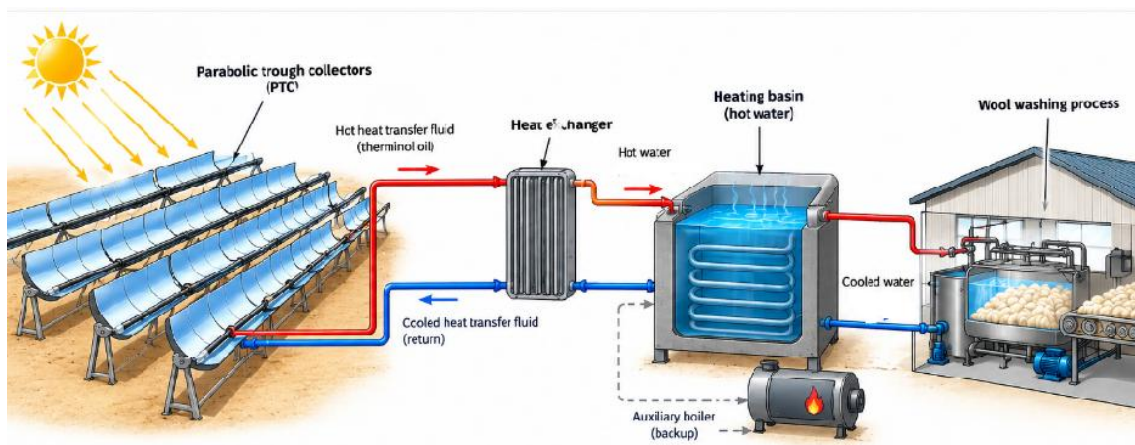


Fig.1 Schematic of a Parabolic Trough Solar Thermal System for Wool-Washing Process Heat Supply

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Application of solar-driven Advanced Oxidation Processes for aquaculture wastewater treatment at neutral pH

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Pollution from aquaculture, industry activities and agriculture is putting an increasing strain on this finite supply of freshwater. Because of its complex composition, which includes organic matter, minerals, pharmaceutical residues (such as antibiotics) and pathogenic bacteria, aquaculture wastewater, in particular, poses a serious environmental risk. The inability of traditional wastewater treatment methods to effectively eliminate persistent organic contaminants emphasizes the need for innovative and environmentally friendly treatment technologies. This study explored the treatment of an aquaculture effluent to remove representative organic contaminants (caffeine, sulfapyridine, sulfamethoxazole, trimethoprim and flumequine) by a solar driven photo-Fenton-like process at neutral pH. This method takes advantage of natural solar irradiation to maintain the Fe(III)/Fe(II) redox cycle while enhancing radical-based oxidation. In order to facilitate the generation of the reactive sulfate radicals to the efficient degradation of resistance substances at neutral pH, persulfate activation mediated by a commercial iron fertilizer (Fe³⁺-IDHA) based on iminodisuccinic acid (IDS) complex was used.

The biodegradable complex would increase iron stability at neutral pH, inhibit precipitation, and maintain catalytic activity during the treatment process [1].

Water chlorination is a frequently used procedure for wastewater disinfection because of its high microbial inactivation effectiveness with a low cost of operation, but it shows a limited efficiency to remove organic contaminants. The limit of using only chlorination towards persistent organic compounds, emphasizes the importance of advanced oxidation processes using solar energy as additional solutions for a thorough wastewater treatment. The match between chlorine absorption and solar spectra led to radical species generation (HO· and Cl·) which play a critical role in overcoming kinetic limitation observed under dark oxidation, greatly increasing pollutant removal rates [2], according to experiments performed using both simulated and real aquaculture wastewater.

A simulated aquaculture wastewater, prepared daily, was used for the solar-driven photo-Fenton-like experiments, which were carried out under natural sunlight in a magnetically stirred open glass reactor (water height of 5 cm and volume of 1.3L) for 60 minutes. Solar chlorination experiments were performed using real aquaculture wastewater, also under natural sunlight in a raceway pond reactor (water height of: 5cm and volume of :17 L), for the same treatment duration.

In all experiments, the initial concentration of each target contaminant was fixed at 100 µg/L.

The degradation of target contaminants was analyzed by Ultra-Performance Liquid Chromatography with Ultraviolet-Diode Array detection (UPLC-UV-DAD).

The investigated solar-driven treatment strategies are summarized in Fig.1.

The results showed that solar-driven Fe-based persulfate activation at neutral pH and solar chlorination to treat aquaculture wastewater are effective, simple, and environmentally friendly processes, pending a deeper study to determine true kinetics and efficiency under different operational conditions. The processes studied are promising for a future reuse of aquaculture wastewater, especially in regions where there is a lot of sun and water scarcity.

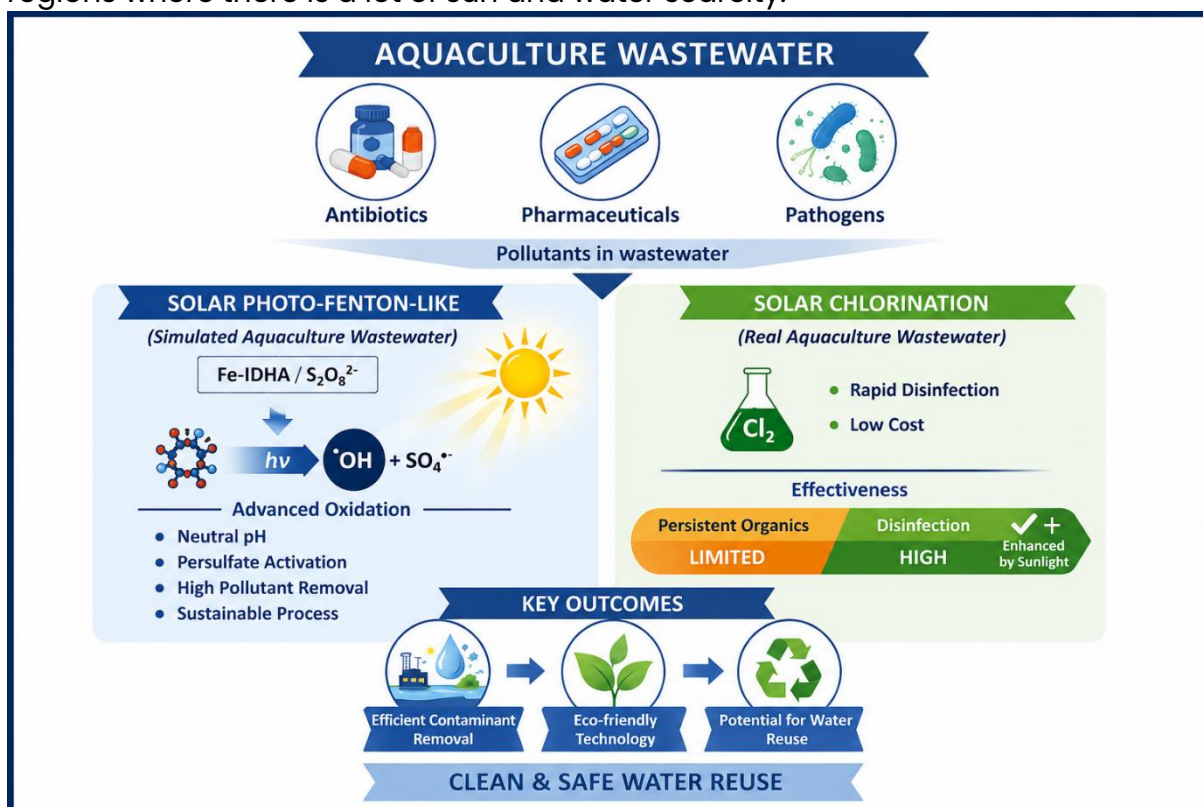


Fig.1. Solar treatment of aquaculture wastewater.

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Solar–Chlorine Disinfection of Simulated Aquaculture Effluent at lab–pilot scale

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Introduction

Water scarcity and increasing water demand have intensified interest in wastewater reuse, particularly in aquaculture. However, wastewater may contain pathogenic microorganisms that require efficient disinfection before reuse. Advanced oxidation processes (AOPs) provide an alternative by generating reactive oxygen species (ROS), which enhance microbial inactivation while reducing chemical demand [1]. Among them, the combination of solar irradiation and free chlorine promotes the generation of highly reactive radicals, allowing lower chlorine doses and shorter treatment times [2,3]. This study evaluates the solar/free chlorine process for bacterial inactivation in simulated aquaculture effluent at laboratory and pilot scale.

Materials and Methods

Simulated aquaculture effluent was prepared following a standardized formulation. Laboratory experiments were performed in 250 mL Duran glass reactors, while pilot-scale experiments were conducted in a 17 L Raceway Pond Reactor (RPR) under natural sunlight. Three bacterial strains (*Escherichia coli* K12, *Edwardsiella tarda*, and *Klebsiella pneumoniae*) were evaluated. Free chlorine concentrations between 0.5 and 10 mg/L were tested under dark and solar conditions. Bacterial inactivation was determined by standard plate count and expressed as log reduction values (LRV). Free chlorine concentration, solar UVA irradiance, temperature and pH were monitored throughout the experiments.

Results and Discussion

Solar irradiation significantly enhanced chlorine disinfection compared with dark conditions. At laboratory scale, complete bacterial inactivation (>5 LRV) was achieved within 30 min using 2.5 mg/L free chlorine under solar irradiation, whereas the same treatment required 60 min in the dark. Increasing chlorine concentration to 5 mg/L further accelerated inactivation. Solar treatment alone produced limited bacterial reduction (Fig. 1 (a)).

Pilot-scale experiments showed the same trend. At 2.5 mg/L, complete inactivation was achieved after 60 min for *E. coli* and *K. pneumoniae*, 30 min for *E. tarda*. Using 5 mg/L reduced treatment times to 15, 25 and 10 min, respectively (Fig. 1 (b)). Among the tested bacteria, *K. pneumoniae* was the most resistant, whereas *E. tarda* was

the most sensitive. Faster chlorine consumption under solar irradiation further confirmed the contribution of solar-driven reactions to the disinfection process.

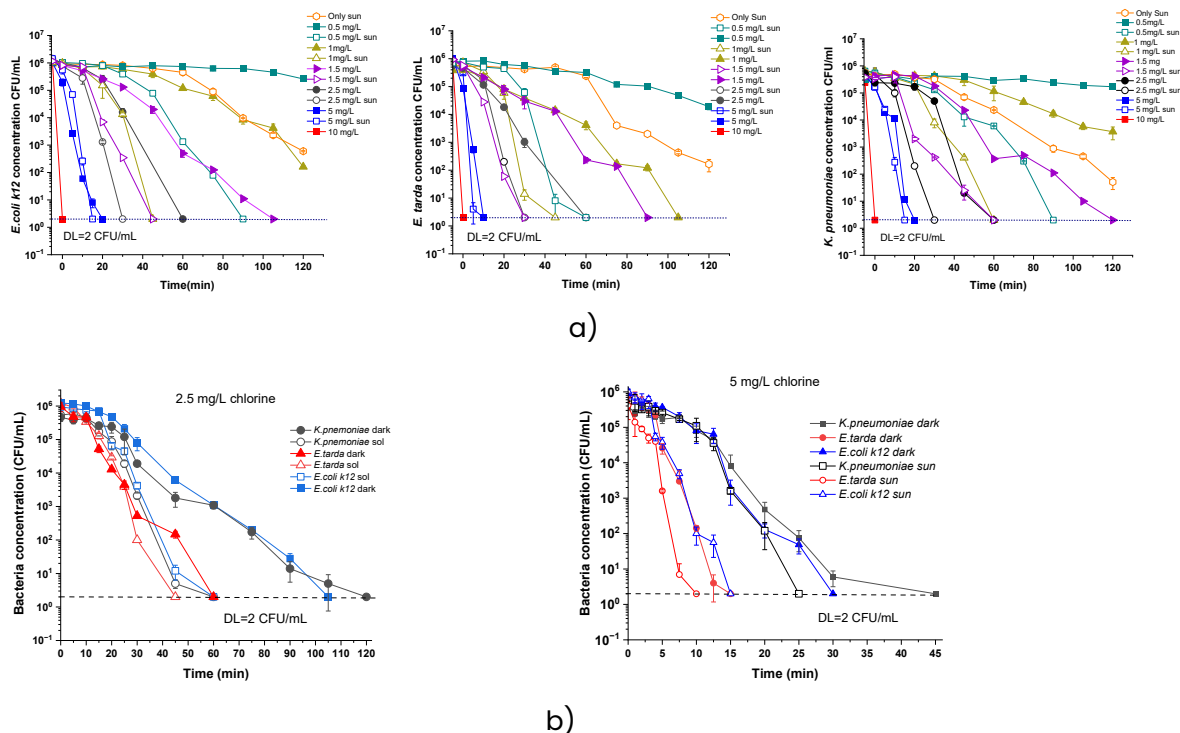


Fig.1 Inactivation profiles of *E. coli*, *E. tarda* and *K. pneumoniae* in SAE under dark and solar conditions with different free chlorine concentrations at lab scale (a) and pilot-scale (b).

Conclusions

The combined solar/free chlorine process substantially improved bacterial inactivation compared with chlorination or solar irradiation alone. Efficient disinfection was achieved at relatively low chlorine doses, reducing treatment time and chemical demand. These findings demonstrate the potential of solar-assisted chlorination as a sustainable and cost-effective technology for aquaculture wastewater treatment and water reuse.

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BRINE CONCENTRATION BY MULTI-EFFECT SOLAR DISTILLATION

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The growing demand for freshwater resulting from the intensification of agricultural and industrial activities represents a global challenge, particularly in regions experiencing high water stress. Consequently, seawater desalination has become a predominant alternative for freshwater production. Reverse osmosis (RO) accounts for more than 85% of the world's installed desalination capacity [1]. However, these systems face a major technological challenge associated with the discharge of large volumes of concentrated brine. Therefore, improving the sustainability of desalination processes is essential, with the aim of increasing freshwater production while reducing brine discharge and moving towards minimum liquid discharge (MLD) and, ultimately, brine recovery and valorization [2]. In this context, solar thermal energy-driven distillation systems represent technically and environmentally viable alternative for brine management [3]. In this research, different multi-effect distillation pilot plants were characterized at the facilities of the Plataforma Solar de Almería (CIEMAT-PSA). The first is a vacuum multi-effect membrane distillation plant (VMEMD) with a membrane surface area of 6.72 m². The second is a film vacuum multi-effect distillation plant (FVMED). The experimental results showed that the output variables of the two pilot plants exhibited different behaviors under the same operating conditions. Variations of approximately 10% were observed in the recovery ratio (RR) and distillate flow rate, while differences of approximately 30% were observed in the specific thermal energy consumption (STEC). Regarding distillate quality, both pilot plants achieved conductivity values ranging from 10 and 50 μScm^{-1} for constant feed concentrations between 35 and 160 gL⁻¹. Furthermore, the FVMED pilot plant demonstrated higher thermal efficiency, achieving an STEC of 200 kWh·m⁻³ at a feed concentration of 70 gL⁻¹ and a temperature of 80 °C. Under the same operating conditions, the VMEMD pilot plan exhibited an STEC of 305 kWh·m⁻³.

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