EuroSun2026

SCALE-UP AND INTEGRATION OF SOL–GEL SELECTIVE COATINGS IN PARABOLIC TROUGH COLLECTORS FOR MEDIUM-TEMPERATURE SOLAR HEAT

Summary

We present the scale-up of sol–gel selective absorber coatings from laboratory to industrial production, yielding 3 m tubes with solar absorptance of 0.945 and emissivity of 0.17 at 300 °C. The coated tubes were welded to form a 6m long receivers and integrated into parabolic trough collectors. A 44 m² rooftop parabolic trough field was installed at a life sciences facility and solar steam generation was demonstrated. Simulations show that north–south orientation maximizes annual yield, while east–west enhances winter production. The pilot is estimated to produce ~16 MWh/year; full rooftop deployment could cover up to 41 % of the building's 822 MWh sterilization demand.

Keywords: Solar thermal, Steam generation,, PTC, Process heat, Decarbonization.

Field of application for the findings: Medium-temperature industrial process heat and laboratory sterilization.

Addressed audience: Researchers and engineers in solar thermal energy and sustainable facility management.

1. Introduction

Decarbonizing industrial and academic facilities is a crucial component of global climate mitigation strategies, as a significant portion of final energy consumption is associated with heat supply rather than electricity. In particular, heat used in the medium-temperature range (100–250 °C) accounts for a considerable share of industrial and institutional energy demand, yet remains difficult to decarbonize due to its reliance on combustion of fossil fuels and limited alternatives suitable for continuous, high-temperature operation [1], [2], [3]. Applications such as sterilization, washing, and drying require continuous and reliable heat supply, and are typically served by natural gas or oil boilers, leading to persistent carbon emissions[1], [3],[4]. In life sciences infrastructures, sterilization alone can represent a substantial and continuous load, often reaching hundreds of megawatt hours per year, highlighting the relevance of medium-temperature heat beyond industrial contexts. Solar thermal technologies offer a direct route to renewable heat production in this temperature range, with concentrating collectors being particularly suitable for generating pressurized hot water or steam compatible with existing infrastructure[5], [6], [7][6], [8], [9], [10]. However, their deployment in built environments remains constrained by integration challenges, available space, and the need for robust operation under non ideal conditions. In rooftop installations, systems must be compact, reliable, and compatible with existing building constraints. A key technological limitation lies in the receiver design. While many selective absorbers are optimized for operation under vacuum, certain applications, such as lightweight parabolic trough collectors (PTCs), require absorber tubes that can operate efficiently and durably in air at elevated temperatures. This constraint places strong demands on the thermal stability and oxidation resistance of the coating. In particular, PTCs, such as those developed by Absolicon, rely on solar absorber tubes exposed to air, requiring coatings that maintain high absorptance and low emissivity under prolonged thermal stress. Among different materials, spinel oxide coating have demonstrated excellent optical performances and high resistance to thermal oxidation[11], [12], [13]. The ability to scale such coatings from laboratory samples to meter-long tubes while preserving performance is therefore a key step toward practical implementation. A recent study systematically investigated the parameters affecting coating quality and performance during the scale-up of these materials [14]. In the work described here, a sol–gel selective coating process is scaled up from laboratory substrates to 3 m long stainless-steel tubes designed for operation in air, and integrated into PTCs installed on the flat rooftop of a life sciences facility, with the objective of supplying medium-temperature process heat for sterilization. Solar steam generation is experimentally demonstrated, and numerical simulations are used to assess the system performance and evaluate the potential of full rooftop deployment. This approach establishes a clear pathway from material development to system integration for renewable medium-temperature heat production in constrained urban environments.

2. System Design and Methods

Selective absorber coatings were fabricated using a sol–gel route and deposited onto stainless steel receiver tubes. The laboratory process, already described in previous publication [14], was transferred to an industrial coating line located at a Spin-off partner, enabling the fabrication of absorber tubes up to 3 m in length. Coatings were applied on polished stainless-steel substrates (1.4301) and thermally treated at 400 °C. Optical characterization was performed through reflectance measurements over the 0.4–14 µm range, using an Oriel MultiSpec 125™ and Cary 5 spectrophotometer with integrating sphere (0.4–2.5 µm) and a Varian 3100 FT-IR (2.5–14 µm). Solar absorptance (α_{sol}) and total hemispherical thermal emittance (ε_{th}) at 573.15 K were derived from the measured spectra according to equations 1 and 2, respectively.

$$\alpha_{sol} = \frac{\int_{0.4\mu m}^{2.5\mu m} I_{sol}(\lambda)(1-\rho(\lambda))d\lambda}{\int_{0.4\mu m}^{2.5\mu m} I_{sol}(\lambda)d\lambda}$$
(eq.1)

$$\varepsilon_{th} = \frac{\int_{2.5\mu m}^{14\mu m} \varepsilon(\lambda)E_b(\lambda,T)d\lambda}{\int_{2.5\mu m}^{14\mu m} E_b(\lambda,T)d\lambda} \quad \text{(eq.2)}$$

The coated tubes were welded to form a 6m long receiver units and integrated into eight Absolicon T160 PTC. Based on these PTCs a solar field of approximately 44 m² with single-axis tracking was installed on the rooftop of the target facility. Annual energy yield simulations were performed in Polysun over a full annual cycle, evaluating different collector orientations (north–south and east–west) and field sizes, for both the pilot installation and a full rooftop deployment scenario.

3. Results and Conclusions

A full scale-up of the selective coating process was achieved by transferring the laboratory deposition method to an industrial production line, enabling the fabrication of absorber tubes up to 3 m in length. The resulting coatings exhibited optical properties comparable to laboratory-scale samples, with an average solar absorptance of 0.945 and an average total hemispherical emissivity of 0.17 at 300 °C. Figure 1 presents representative quality control data from the production line, showing the averaged optical performance measured over a 3 m tube, with consistent values along the receiver length. These results confirm that the sol–gel process can be reliably extended to full scale receiver geometries without significant loss of performance. Ageing tests confirm high resistance to thermal degradation, with results to be reported in a forthcoming publication, indicating stable performance over an estimated lifetime of up to 25 years at 310 °C. The scaled-up tubes were assembled into 6 m long receiver units through welding and integrated into parabolic trough collectors. Figure 2 shows one of the 6 m long receivers, where the welding joint is visible as a thin line, demonstrating the mechanical robustness and integrity of the coating. Solar steam production was demonstrated, confirming the operability of the developed receivers in a concentrating solar field. The solar field potential was further assessed through numerical simulations of different collector configurations and orientations, as shown in Figure 3. A north–south orientation of the parabolic trough collectors was found to maximize annual energy yield, providing approximately 33 % higher production compared to east–west alignment. Conversely, east–west orientation significantly enhances winter performance, with seasonal production up to 2–4 times higher during winter months. These results highlight the importance of field design tailored to specific demand profiles. The addition of four collectors was shown to increase monthly energy production by approximately 35 %, while preserving the overall seasonal production trend. The current pilot installation is estimated to produce approximately 16.14 MWh of thermal energy per year. Simulations of full rooftop deployment indicate a potential annual production of up to 340 MWh, depending on the collector configuration and orientation. For reference, the building on which the pilot solar field was installed has an annual sterilization energy demand of 822 MWh, meaning that full deployment could potentially cover up to 41 % of this demand with renewable solar steam. These results establish a complete and validated pathway, from sol–gel coating development to industrial scale-up, system integration, and field-level energy assessment, toward the deployment of concentrating solar technology for renewable process heat in industrial and urban environments.

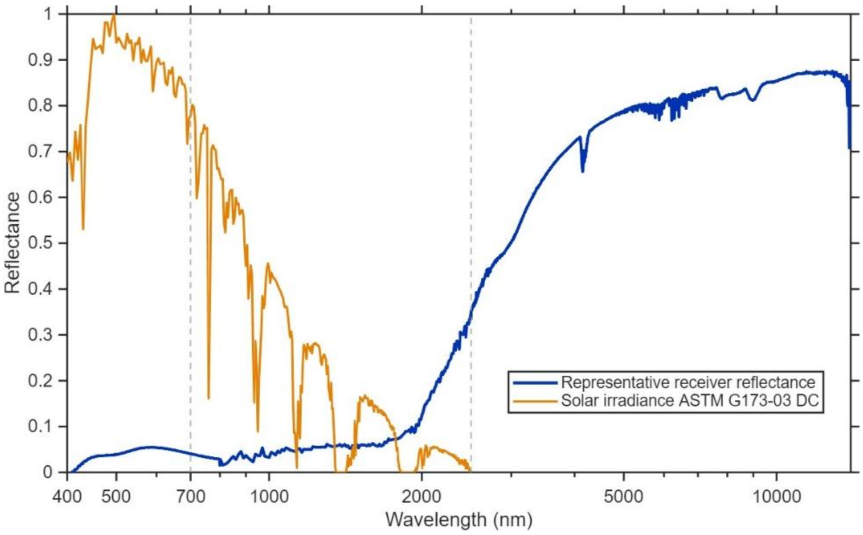

Figure 1. Representative receiver tube reflectance. The data shows high solar absorption in both visible and near-infrared regions, and low emissivity in far-infrared region.

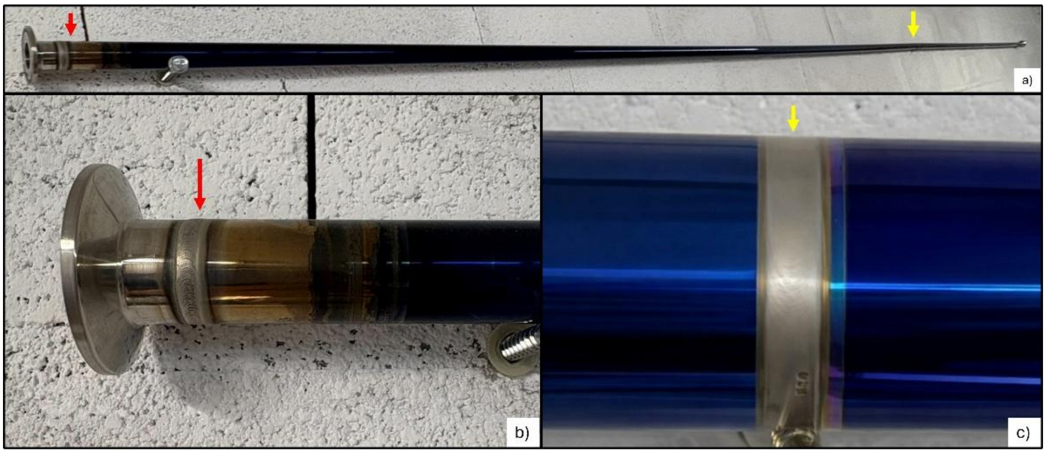

Figure 2. Two tubular receivers welded together to form a 6 meter long receiver, then assembled in the PTCs collectors. Details of flanges (b, red arrow) and the welding of the two tubes (c, yellow arrow).

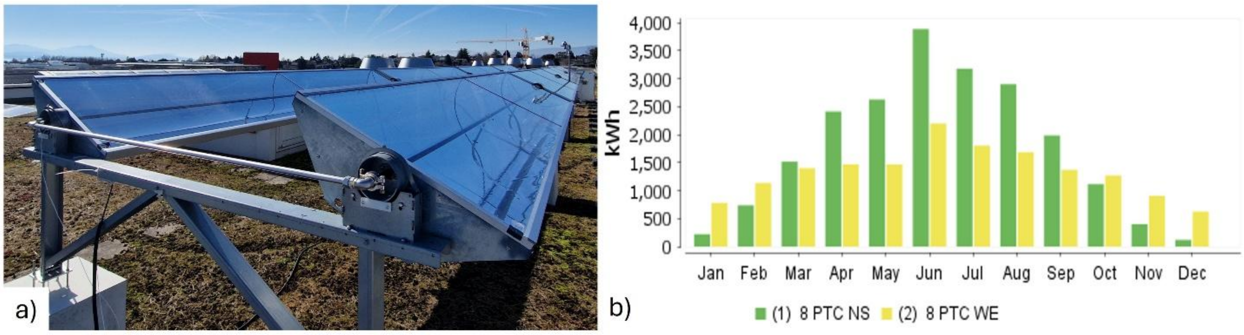

Figure 3. The PTC field installed on the rooftop (a) and the simulated annual production of the solar field, comparing both north-south orientation (NS) and west-east (WE) (b).

4. References

[1] Y. Tian and C. Y. Zhao, “A review of solar collectors and thermal energy storage in solar thermal applications,” *Appl. Energy*, vol. 104, pp. 538–553, 2013, doi: 10.1016/j.apenergy.2012.11.051.
[2] W. Weiss and M. Spörk-Dür, “Edition 2023 Global Market Development and Trends 2022 Detailed Market Figures 2021 SOLAR HEAT WORLD WIDE”, doi: 10.18777/ieashc-shw-2022-0001.
[3] W. Weiss and M. Spörk-Dür, “Edition 2022 Global Market Development and Trends 2021 Detailed Market Figures 2020 SOLAR HEAT WORLD WIDE”, doi: 10.18777/ieashc-shw-2022-0001.
[4] S. A. Kalogirou, “Solar thermal collectors and applications,” 2004. doi: 10.1016/j.pecs.2004.02.001.
[5] A. Fernández-García, E. Zarza, L. Valenzuela, and M. Pérez, “Parabolic-trough solar collectors and their applications,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 7, pp. 1695–1721, 2010, doi: 10.1016/j.rser.2010.03.012.
[6] J. A. . Duffie and W. A. . Beckman, *Solar engineering of thermal processes*. Wiley, 2013.
[7] Roland. Winston, J. C. . Miñano, Pablo. Benítez, and W. T. . Welford, *Nonimaging optics*. Elsevier Academic Press, 2005.
[8] J. D. Gil, A. Topa, J. D. Álvarez, J. L. Torres, and M. Pérez, “A review from design to control of solar systems for supplying heat in industrial process applications,” Jul. 01, 2022, *Elsevier Ltd*. doi: 10.1016/j.rser.2022.112461.
[9] N. Pardo, J. A. Moya, and K. Vatopoulos, “Prospective Scenarios on Energy Efficiency and CO 2 Emissions in the EU Iron & Steel Industry”, doi: 10.2790/64264.
[10] S. Madeddu *et al.*, “The CO2reduction potential for the European industry via direct electrification of heat supply (power-to-heat),” *Environmental Research Letters*, vol. 15, no. 12, Dec. 2020, doi: 10.1088/1748-9326/abbd02.
[11] M. Joly *et al.*, “Novel black selective coating for tubular solar absorbers based on a sol-gel method,” *Solar Energy*, vol. 94, pp. 233–239, Aug. 2013, doi: 10.1016/j.solener.2013.05.009.
[12] M. Joly *et al.*, “Optical and structural analysis of sol-gel derived Cu-Co-Mn-Si oxides for black selective solar nanocomposite multilayered coatings,” *Solar Energy Materials and Solar Cells*, vol. 143, pp. 573–580, 2015, doi: 10.1016/j.solmat.2015.06.058.
[13] A. Krammer, M. Lagier, and A. Schüler, “In-line electronic and structural characterization of reactively sputtered Cu-Co-Mn black spinel oxides,” *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, vol. 39, no. 5, Sep. 2021, doi: 10.1116/6.0001120.
[14] F. Turci, M. Lagier, A. Krammer, and A. Schüler, “Impact of relative humidity on the optical properties of sol–gel processed black spinel oxide coatings for solar absorbers,” *Next Materials*, vol. 11, Apr. 2026, doi: 10.1016/j.nxmate.2026.101643.