Solar World Congress 2025

Solar heat for a hot dip galvanizing process using linear Fresnel collectors and packed bed thermal energy storage

Summary

Galvanized steel is essential in various industries for corrosion-resistant structures. Its production requires a process that demands high-temperature heat commonly supplied by gas burners. To support industry decarbonization, the present study explores the implementation of a heating system based on linear Fresnel collectors working with solar salt, and coupled to a thermocline packed-bed thermal energy storage system (PBTES). A thermodynamic model using the TESPy library was implemented to assess the performance of a plant located in Santiago, Chile, comprising a solar collector field of 850 m² of aperture area and indirect PBTES, filled with copper slag as storage media. The model allowed the evaluation of year-round performance with PBTES volumes ranging from 5.3 m³ to 261.3 m³. The results show effective daytime solar heat provision, complemented by nighttime discharge from PBTES, promoting a continuous operation. A parametric analysis revealed that a peak effective solar fraction of 37.23% was achieved at a storage volume of 12.6 m³.

Keywords: Galvanizing, industrial solar heat, packed-bed storage, Fresnel collectors

1. Introduction

Galvanized steel is a crucial material for construction across several industries. The galvanization process consists of applying a coat of zinc to steel pieces to increase durability and avoid corrosion. The coating is typically applied through a hot dip process, which consists of a pool of molten zinc that must be maintained at a temperature of 450°C, commonly using gas burners to control the temperature (Blakey and Beck 2004).

The galvanizing industry can be included in the decarbonization pathways since its fossil fuel consumption could be directly replaced by clean technologies. Due to the high temperature of the process, concentrating solar thermal systems are suitable, as they can deliver heat at the required temperature. Dedicated heat transfer fluids (HTF) that can work at high-temperatures must be assessed, such as molten salts, which have been evaluated with successful results in Fresnel collectors delivering heat to a Rankine cycle (Bonini, Starke, and da Silva 2024).

Thermal energy storage (TES) systems can increase the technical and economic viability of solar thermal systems, especially when using packed-bed (PBTES) technology (Battisti, de Araujo Passos, and da Silva 2021). Furthermore, solid-state TES, such as packed-bed technology, presents high compatibility with the metallurgical industry due to the high-temperature processes that features the heat demand of the processes (Wolde, Cardemil, and Escobar 2024).

2. Methodology

The present article describes the assessment of a solar thermal plant, coupled with an indirect PBTES, meant to deliver thermal energy to a hot dip galvanizing process. The layout of the plant is described in Fig. 1. The PBTES unit is connected indirectly to the heat delivery network and can work with a different HTF. A backup heater is included to ensure that the temperature provided for the process is constant. A linear Fresnel solar field is used as a clean heat source, with a constant aperture area of 850 m^2. A defocusing strategy is considered to limit the energy provided by the solar field. The PBTES is designed as a thermocline tank with a constant aspect ratio (AR=2) and uses copper slag as the storage material due to its high thermal capacitance (Segovia A. et al. 2025). The solid pebbles have a diameter of 0.07 m, and the system presents a void fraction of 0.4.

A thermodynamic model of the plant is configured using the TESPy library in Python (Witte and Tuschy 2020), while the PBTES is modeled using an analytic solution of the energy equation (Calderón-Vásquez et al. 2024), taking into consideration the heat losses. The model is assessed in a year-long simulation using hourly data from a TMY file for Santiago, Chile. A parametric analysis is performed for a range of TES volumes ranging from 5.3 m^3 to 261.3 m^3 and using solar salt as the HTF. The results of the parametric analysis are compared in terms of the effective solar fraction (ESF) of the plant, defined as

$$ESF = \frac{Q_{sf}}{Q_{sf}+Q_h+W_p} \quad \text{(eq. 1)}$$

where Q_{sf} is the solar field heat input, Q_h is the preheater heat demand, and W_p is the work consumed by the pumps.

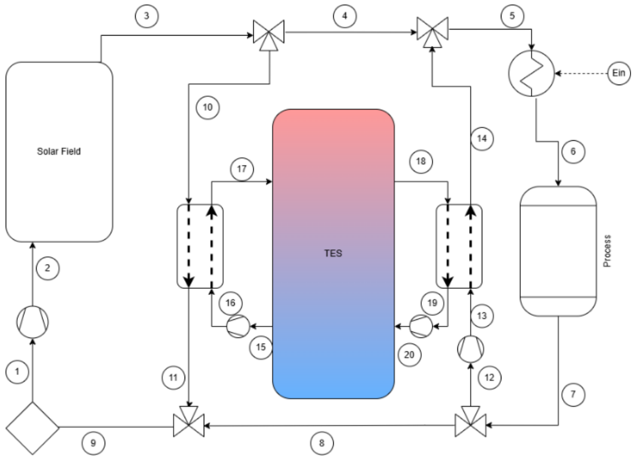

Fig. 1: Layout of the solar thermal system coupled with an indirect PBTES

The control logic divides the operation of the plant into six modes: Mode 1 is for high irradiation moments and discharged PBTES, in which the amount of heat delivered to the process is exactly the heat demand, and the surplus heat is delivered to charge the PBTES, by means of a three-way valve. Mode 2 is for high irradiation moments; and fully charged PBTES, when the defocusing strategy is applied as a curtailment strategy for the heat surplus. Mode 3 is for low irradiation moments, in which the PBTES is discharged to deliver heat to the process. Mode 4 is for low irradiation moments in which the PBTES is fully discharged, thus the preheater delivers the complete heat load. In case the TES lower region is at a temperature below a defined range, all the solar heat is delivered to the PBTES unit (mode 5), or a de-stratification process is applied to increase the temperature of the lower zone in the PBTES (mode 6).

3. Results

A single case of the solar plant is presented to describe the operation in detail when considering a TES volume of 24.5 m^3. Fig. 2 shows the results in terms of energy provided to the plant and temperatures inside the PBTES unit for the first 5 days of operation. The uniform energy profile delivered by the solar field indicates that the irradiation is from fully clear days. The preheater energy profile shows that during the day, the solar field provides all the energy requirements for the operation of the process. On the other hand, during the night, it is observed the discharge of the PBTES as the energy demanded from the preheater increases until it reaches a constant level. This response is verified by analyzing the temperature profile in the PBTES, as the high-temperature zone in the upper part of the storage unit is used as the heat source for the discharge process in Mode 3. As the outlet temperature in this area decreases, the heat delivered by the preheater increases.

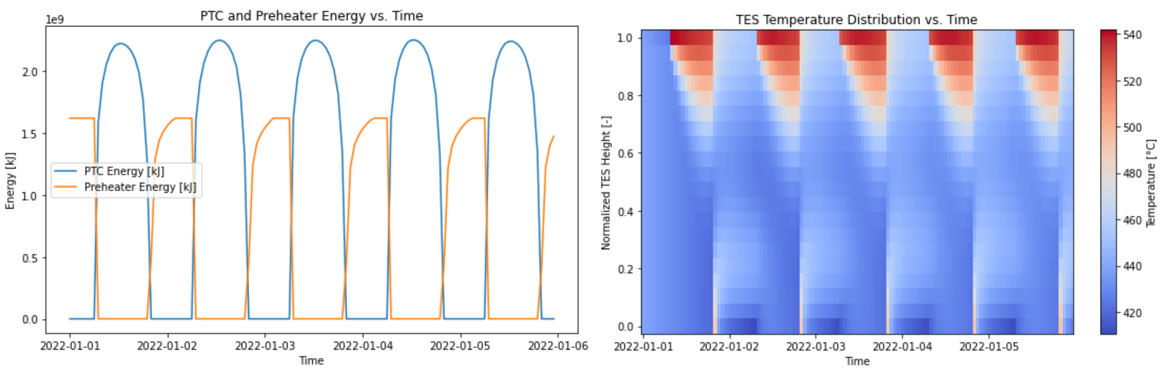

Fig. 2: Energy profiles of the PTC field and the preheater unit (left) and temperature profile of the PBTES unit (right) for the first 5 days of the simulated year.

Fig. 3 shows the parametric analysis results for several TES volumes, including a base case without storage.

Including a PBTES unit for extending the operation of the solar system through the night can enhance the solar fraction, displaying peak value at relatively low TES volumes. The highest solar fraction obtained is 37.23% at TES 2, which represents a volume of 12.6 m^3. A decrease in the solar fraction can be seen for larger TES volumes due to the heat losses in the storage tank that induce larger periods of TES charging, reducing the actual input of solar heat to the process.

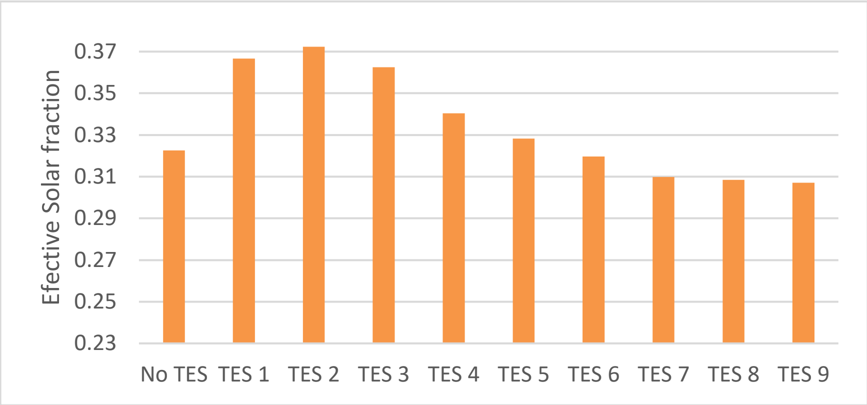

Fig. 3: Results of the parametric analysis.

4. Conclusions

The hot dip galvanizing process presents an important demand for high-temperature heat, and a solar heating system can tackle an important part of the associated fossil fuel consumption. Using a single thermocline tank is feasible for a high-temperature heat delivery system which can enhance the operation of the solar plant. A technology such as PBTES can be indirectly integrated to absorb high-temperature peaks and extend the operation beyond the day. The use of high-density HTF, such as solar salts, can further increase the availability of solar heat in the system.

Future work should include an economic assessment of the options in TES volume and HTF, as the cost of components such as heat exchangers and pumps might present variations.

5. References

Battisti, F. G., L. A. de Araujo Passos, and A. K. da Silva. 2021. “Performance Mapping of Packed-Bed Thermal Energy Storage Systems for Concentrating Solar-Powered Plants Using Supercritical Carbon Dioxide.” *Applied Thermal Engineering* 183 (116032): 116032.

Blakey, S. G., and S. B. M. Beck. 2004. “Energy Consumption and Capacity Utilization of Galvanizing Furnaces.” *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering* 218 (4): 251–59.

Bonini, Vinicius R. B., Allan R. Starke, and Alexandre K. da Silva. 2024. “A Technical-Economic Analysis and Optimization of a Direct Molten Salts Linear Fresnel Plant.” *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 46 (8): 510.

Calderón-Vásquez, Ignacio, F. G. Battisti, Marco Rosales-Vera, José M. Cardemil, and Rodrigo Escobar. 2024. “On the Analytical Solution of the One-Dimensional Convection–Conduction Equation for Packed-Bed Thermal Energy Storage Systems.” *Thermal Science and Engineering Progress* 55 (102888): 102888.

Segovia A., Valentina, José Miguel Cardemil, Mamié Sancy, and Rodrigo Escobar. 2025. “Analysis of Copper Slag from a Chilean Foundry for Application as Filler Material in Thermal Energy Storage Systems.” *Journal of Energy Storage* 111 (115281): 115281.

Witte, Francesco, and Ilja Tuschy. 2020. “TESPy: Thermal Engineering Systems in Python.” *Journal of Open Source Software* 5 (49): 2178.

Wolde, Ian, José M. Cardemil, and Rodrigo Escobar. 2024. “Compatibility Assessment of Thermal Energy Storage Integration into Industrial Heat Supply and Recovery Systems.” *Journal of Cleaner Production* 440 (February): 140932.