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SHIPCAL-CL: IMPROVING THE SIMULATION OF SOLAR THERMAL SYSTEMS FOR INDUSTRIAL PROCESSES IN CHILE

Summary

Despite its potential for decarbonizing industrial heat production, solar thermal energy has very little market penetration. This is also the case in Chile, despite the privileged solar potential of this country. To promote the adoption of this technology by industry, the authors have developed a simulation tool that uses state-of-the-art models to estimate its economic and environmental benefits. The platform uses the heat demand of the user to determine the most convenient sizing for the solar thermal system. The models used by the developed tool have been validated against experimental data, showing promising results. Currently, the developing team continues working on improving the simulation platform.

Keywords: Solar Heat for Industrial Processes, SHIP, Solar Thermal Energy, Transient Modeling

1. Introduction

1.1. Motivation

Solar heat for industrial processes (SHIP) could make an important contribution to the decarbonization of the global energy matrix. Nevertheless, a great majority of industrial heat continues to be provided by fossil fuels. According to IEA-ETSAP and IRENA (2015), there are various barriers that hinder the growth of this technology, one of them being the lack of standard guidelines and tools for the design of SHIP systems.

In this regard, Cardemil et al. (2022) compared various platforms for simulating SHIP systems, with the remarkable result that, when these tools were used to simulate the same case, their results differed considerably. This shows that there is a large uncertainty associated with the results of platforms of this type. To get more reliable results, potential users must therefore hire external consultants, which is yet another barrier for SHIP projects.

2.1. Proposal: SHIPcal-CL

Considering the context just presented, the authors of this abstract have developed a novel simulation tool for SHIP systems, called "SHIPcal-CL", which aims to promote the use of this technology among Chilean industries. In comparison to similar web-based free-to-use simulation platforms, this tool aims to be more accurate, thus decreasing the risk associated with investing in such projects, while also being simpler than professional programs that require expertise from the user and much information about the industrial plant. Some of the features of this new simulation platform are as follows:

- It is programmed to work with TMY data files provided by the Ministry of Energy of Chile (see Ref.).
- It relies on state-of-the-art models to perform transient simulations of solar thermal systems.
- It considers the most widely used integration strategies for solar thermal systems into industrial heat supply systems.
- It adapts itself to the knowledge of the user. For instance, it can determine the most convenient size for the solar thermal system based on the current fuel consumption for heat production.
- It considers the daily variability of thermal demand produced by ambient temperature.
- It automatically computes economic and environmental KPIs.
- Some of the models used have been validated against experimental data.

2. Methodology

4.1. Computational models

The two most relevant components of a solar thermal system are the solar field and the thermal energy storage (TES) system. At the moment, SHIPcal-CL is capable of simulating low-temperature solar thermal systems; considering this, the platform includes models for both flat plate collectors and evacuated tube collectors. Regarding the TES system, the platform models stratified thermal storage tanks with water as heat-storage medium.

The models for both types of solar collectors consider the parameters to compute their efficiency with quadratic thermal losses and the "Incidence Angle Modifier" (IAM) factor. In addition to this, the model for flat plate collectors also considers the flow rate correction for efficiency presented by Duffie and Beckman (2006), whereas the model for evacuated tube collectors takes into account the biaxial nature of the incidence angle of the sun on the collector.

One of the novelties of the developed platform is that it takes into account the undesired production of steam inside the collectors due to overheating. In this case, the model assumes that the steam is released through automatic purging valves, which is often the case for low-temperature solar thermal systems, while cold water is injected into the system to replace the lost water.

The stratified storage tank is simulated with a one-dimensional nodal model that estimates each node's transient behavior by analytically solving a simplified version of the original differential equation. This model was discussed by Newton (1995) and is currently used by the TRNSYS software (Solar Energy Laboratory, University of Wisconsin-Madison and Thermal Energy System Specialists, LLC, 2021).

The developers of SHIPcal-CL have also added the "Advanced Flowrate Distribution" (AFD) method to the tank model. This is a novel technique proposed by Saloux and Candanedo (2019) that aims to take into account the buoyancy produced when the flows that enter the storage tank have a temperature different from the tank at the height where the inlet is located.

SHIPcal-CL also uses the algorithm proposed by Jesper et al. (2021) to account for the dependence of heat demand on ambient temperature. Moreover, the platform can model various integration layouts for SHIP systems in industrial heat supply systems. These layouts were obtained from the work of Hassine et al. (2015).

4.2. Experimental validation

For the validation of the flat plate collector model, the authors used experimental data of a solar field that delivers thermal energy to a swimming pool in a university campus. Irradiance, flow rates and flow temperatures were recorded, and then the model was used to predict the thermal power produced by the collectors.

Regarding the validation of the model for stratified storage tanks, the authors considered the data produced by an experimental small-scale stratified tank which had thermocouples at various heights along its central axis. Thus, stratification predicted by the computational model was compared to that of experimental data.

3. Results

The validation of the model for flat plate solar collectors shows promising results. When considering four hours around midday (i.e., two hours before to two hours after), the mean absolute percentage error between predictions and measurements is less than 6%, regardless of the irradiance levels of a particular day.

The validation of the tank model shows that the AFD method is remarkably superior to standard modeling techniques, a claim already made by the creators of that algorithm (Saloux and Candanedo, 2019). Moreover, this new validation was carried out in a tank much smaller than the one used for the original publication of the method, showing the wide range of scales for which the method is valid. Nevertheless, the AFD method requires optimizing one parameter, which makes it a little more complex to apply.

Fig. 1 exemplifies some of the graphical results that the simulation platform can generate. In order to generate those results, a hypothetical industry was considered which is located in Santiago and currently generates all its heat with diesel, having a yearly consumption of 200 diesel tons. On the left side of the figure, a bar plot shows the monthly thermal energy that a solar thermal system could provide to that industry. On the right side of the figure, there is a heat map showing the hours of the day at which the heat is delivered. It is also worth noting that the monthly heat demand was calculated with the algorithm of Jesper et al. (2021).

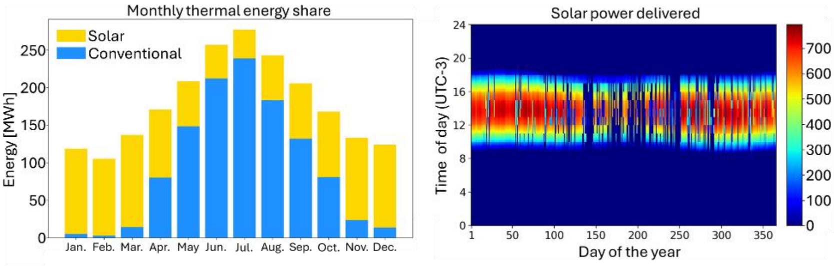

Fig. 1: Graphic results produced by the SHIPcal-CL platform for an industry with a yearly demand of 200 diesel tons

4. Conclusions

The decarbonization of the energy matrix is one of the greatest endeavors of engineering and science nowadays, and SHIP systems could play an important role in this process

SHIPcal-CL aims to be a relevant contributor to the development of SHIP systems in Chile. What has been presented in this document concerns merely the features of the platform that are already programmed and functioning; nevertheless, the developers are still working on making the tool useful for a larger number of users and making it more accurate and reliable.

Thus, work that is already underway involves making the tool public on the internet, with a GUI that makes the user more comfortable when using it. Also, there is the long-term goal of generalizing the tool for other purposes, such as air heating and higher temperature processes.

5. References

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