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Design Factors in Concentrating Solar Power Plants for Industrial Steam Generation

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INTRODUCTION

Industrial consumption accounts for a significant share of total primary energy demand, and thermal energy production for process heat, which represents a large percentage, uses mainly fossil fuels. Consequently, concentrating solar thermal energy for steam production may become a viable renewable alternative in regions with good radiation levels throughout the year.

Recent studies have focused on technical aspects of linear focus technologies: the design and optimization of their components, the analysis and comparison of different configurations, or losses and efficiency. However, there are fewer works focused on the integration of concentrating solar plants in industrial processes.

In this work, the different alternatives currently available are studied, as well as the main design parameters for this type of plant. Besides, a guidance procedure is proposed and applied to a real medium temperature prototype.

MATERIALS AND METHODS

The main factors that affect the design process, the component sizing, and the final behaviour of an industrial steam solar plant are shown in Figure 1.

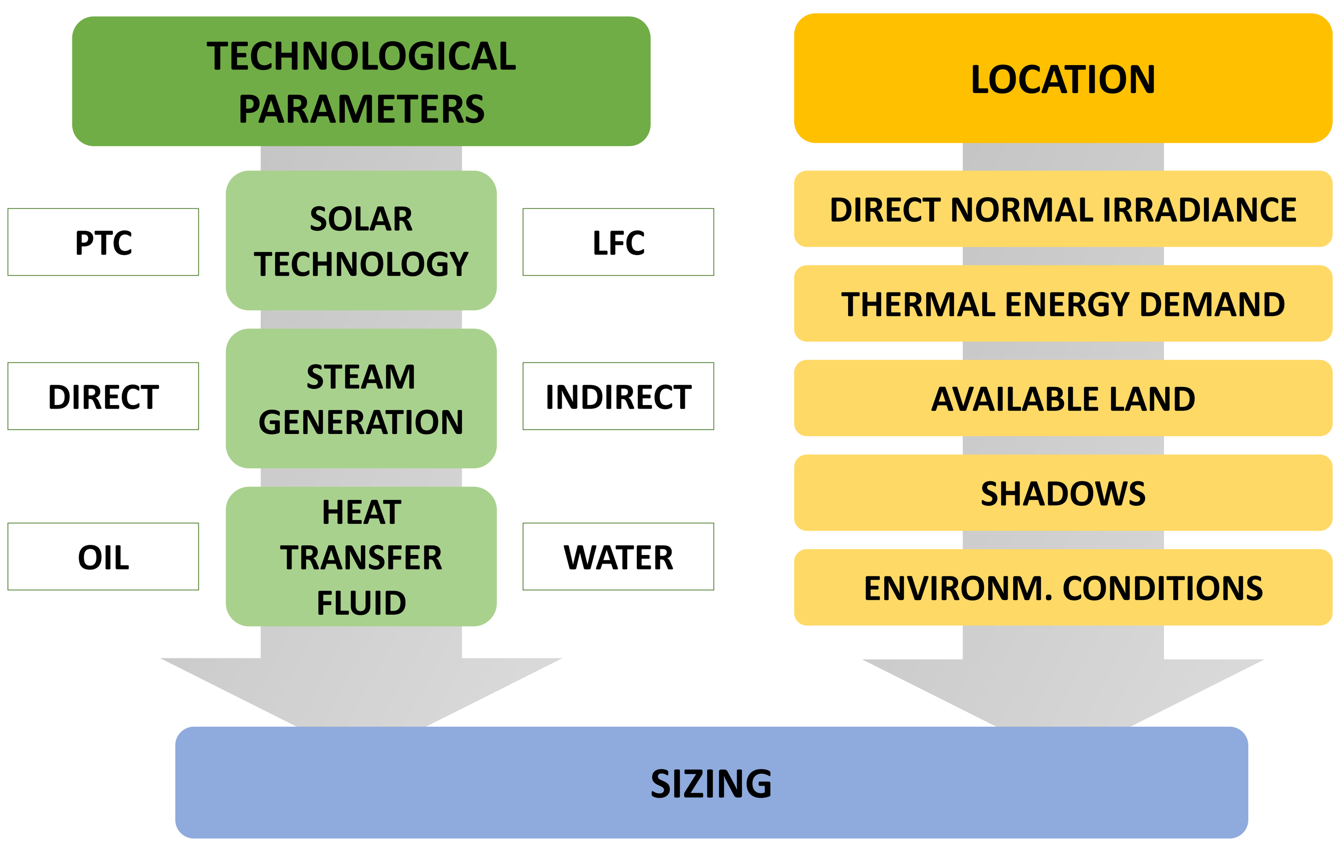

Fig. 1. Main design parameters

A. TECHNOLOGICAL PARAMETERS

1. SOLAR TECHNOLOGY: Direct radiation must be concentrated to achieve conditions suitable to produce steam, so solar tracking mirrors should be used. Linear focus systems (LFC and PTC) are suitable for medium temperature uses, and they strike a balance between cost, complexity, and energy production. LFC have several technical and economical advantages, such as their structural simplicity, smaller size and weight, fewer shadow problems, and a lower cost that compensates for the worse optical performance.

2. STEAM GENERATION SYSTEM: Direct systems need a preheater before the absorber tube and a downstream steam separator, while an indirect system requires a heat exchanger between the primary and secondary circuits, it facilitates process control as there is no phase change in the primary circuit, the exchanger stabilizes production, and a HTF different from water can be used. In industries with low pressure needs, indirect systems will be appropriate as it will be easier to keep the primary pressurized to avoid vaporization of the fluid.

3. HEAT TRANSFER FLUID: The most viable options for industrial uses are water and thermal oils. The latter are flammable, toxic and polluting fluids, but they will be the better choice when high pressures are needed. Otherwise, water should be chosen as it has a good heat capacity, it is safe, and decreases the plant cost.

B. LOCATION

1. DIRECT NORMAL IRRADIANCE: The availability and quality of this resource must be verified. Most of Spain has a Mediterranean-type climate with many sunshine hours, but possible microclimates should be studied using accurate meteorological data from the plant location, and also the local orography, shadows from nearby buildings, and supplies like electricity and water.

2. THERMAL ENERGY DEMAND: It will be difficult to size the plant to fully cover the steam needs, as cost and land availability will be the most limiting factors. An alternative must be available for a correct operation of the industry in the absence of solar radiation. Profitability will depend on the percentage of demand covered, the fuel replaced and its price, seasonality of consumption, or public subsidies.

3. AVAILABLE LAND: Collector dimensions and available land will set the solar field orientation and the number of modules, and thus temperature gradient ΔT and flow rate $\dot{m}$. Once known those parameters, the optical model developed by F.J. Sepúlveda et al can be used to obtain efficiency η_t and solar power P_S:

$$\eta_t = \frac{\dot{m} \cdot C_p \cdot (T_{out} - T_{in})}{Radiation_{theor}}; \qquad P_s = \eta_t \cdot DNI \cdot S_t$$

4. SHADOWS: A specific shadow analysis at the chosen site must be carried out, using a graphical representation of the building profile and a sun path diagram.

5. ENVIRONMENTAL CONDITIONS: Other factors such as wind and dust can affect the performance of the plant, so measures should be taken to protect the mirrors from adverse weather and to clean them properly.

RESULTS

This work focused on the real case of a small experimental prototype in an industry in Cáceres (Extremadura, Spain), which has very favourable radiation conditions. An innovative LFC system was chosen according to the advantages mentioned, as well as an indirect steam generation system with a kettle reboiler type heat exchanger. The HTF chosen was treated water, as the industry requires low pressures (4 bar, which will be increased to 7 bar for testing). The location provided by the industry, shown in Fig. 2, led to a total of 4 collectors with a net area of 26,4 m^2 and an orientation of 135º with respect to the south. These values, along with the analysis of DNI, losses, and efficiency, provided a nominal power of 56.4 kW. Shadows will not be a significant problem, as shown in Fig. 3.

Fig. 2. View of the solar plant

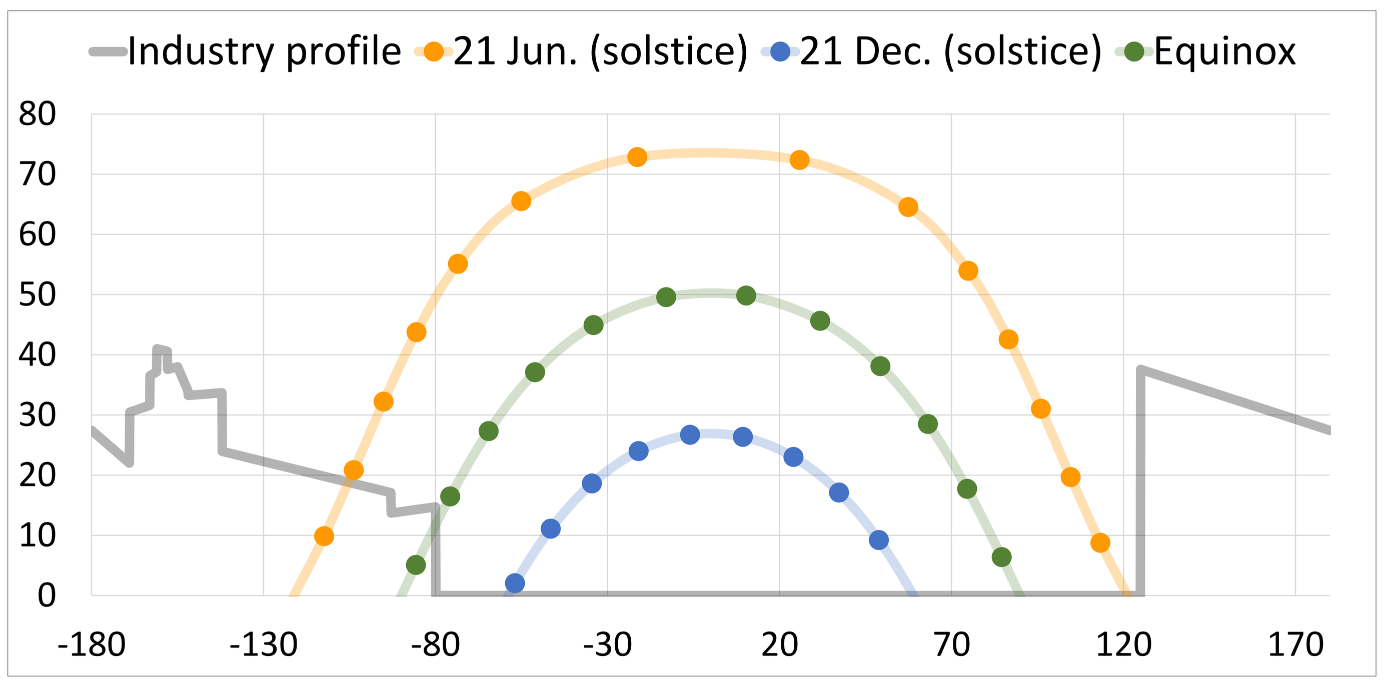

Fig. 3. Sun path and shadow profile of the industry

CONCLUSIONS

The main factors related to the design of concentrating solar plants have been evaluated and applied to a real case, which gave an insight into the constraints an installer will face, resulting in a 56.4 kW prototype.

Fresnel technology meets the needs of industry, is easy to control, and cost-effective. Indirect steam systems and water as HTF are advisable. The most limiting sizing parameter is the available area, and DNI and shadows must be checked.

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