Losing Energy to increase Efficiency – Defocusing Collectors in Concentrated Solar Power Plants

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For an efficient operation of linear concentrating solar systems, a key factor is achieving a high and constant outlet temperature, which is closely linked to effective mass flow control. The mass flow distribution within a solar field is currently generally unknown. This poster illustrates the Time-of-Flight (ToF) method for determining the mass flow of individual loops within a solar field by temporarily focusing and defocusing individual collectors. Knowledge of the mass flow distribution at any time can help to optimize mass flow but also to identify inefficient collectors and thereby improve predictive maintenance.

Background: Concentrating Solar Systems

Concentrating solar thermal systems are used to generate heat by concentrating sunlight (Concentrating Solar Thermal, CST) and, if necessary, to subsequently use this heat for power generation (Concentrated Solar Power, CSP). This concentration can be either point-focused (solar tower or solar dish) or line-focused (parabolic trough collector (PTC) or linear Fresnel collector (LFC)), with the focus of this work being on systems with parabolic trough collectors (see Fig. 1). A thermal storage can be added to the corresponding system to align energy demand with energy supply. To maximize the thermal efficiency of these systems, it is necessary to achieve the highest possible and most consistent temperatures. This not only increases the storage capacity of the thermal storage system but also enhances the efficiency of the subsequent power generation.

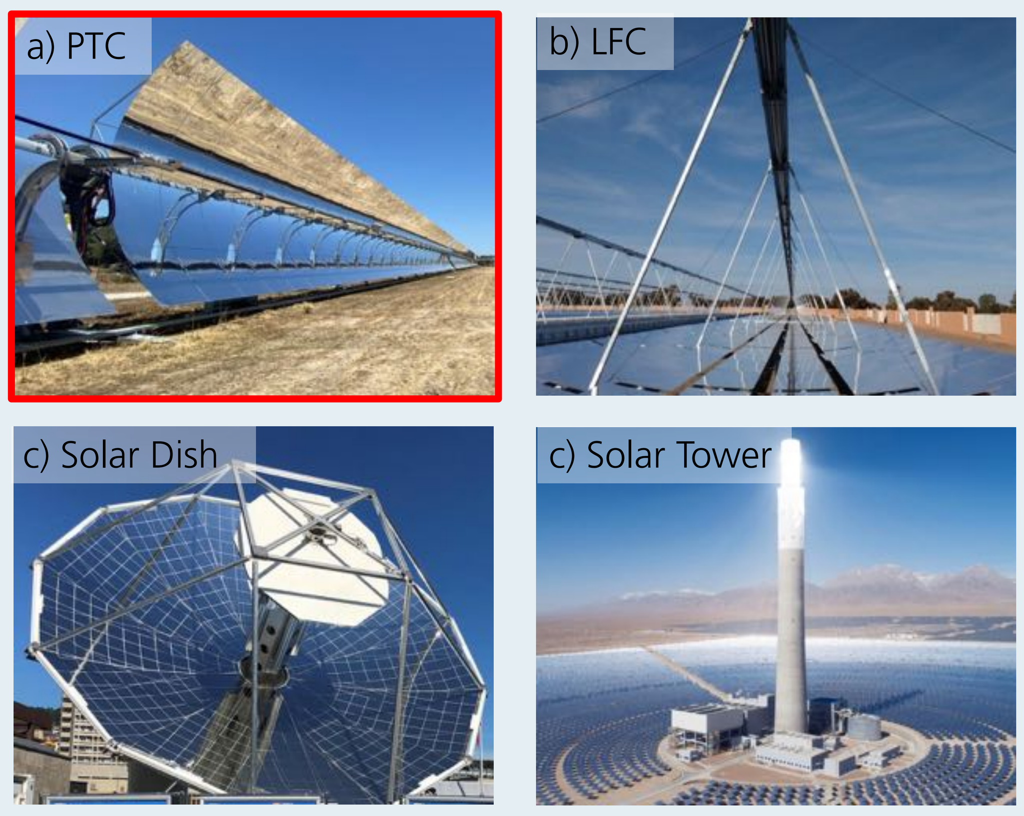

Fig. 1: Pictures of most common linear focusing – a) and b) [1] – and point focusing – c) and d) [2] – concentrated solar systems.

Mass Flow Calculation

Mass flow $\dot{m}$ of a heat transfer fluid (HTF) through a pipe can be calculated using the following equation:

$$\dot{m} = \dot{V} \cdot \rho = v \cdot A \cdot \rho = \frac{\Delta l}{\Delta t} \cdot \frac{\pi}{4} d^2 \cdot \rho(\vartheta)$$

where, the ToF method aims at measuring the time delay Δt of a thermal step response at different collectors with an inner diameter of d and a distance of Δl between the corresponding temperature sensors – considering the density of the used HTF. Using ToF method enables mass flow distribution measurement with high accuracy (measuring 94% of the data within ± 5% of full scale [3]) and offers a huge potential to increase solar field efficiency (due to early heat loss detection and the possibility of improved maintenance) [4]).

To calculate the time delay two different approaches were considered: Peak-to-peak analysis and cross-correlation.

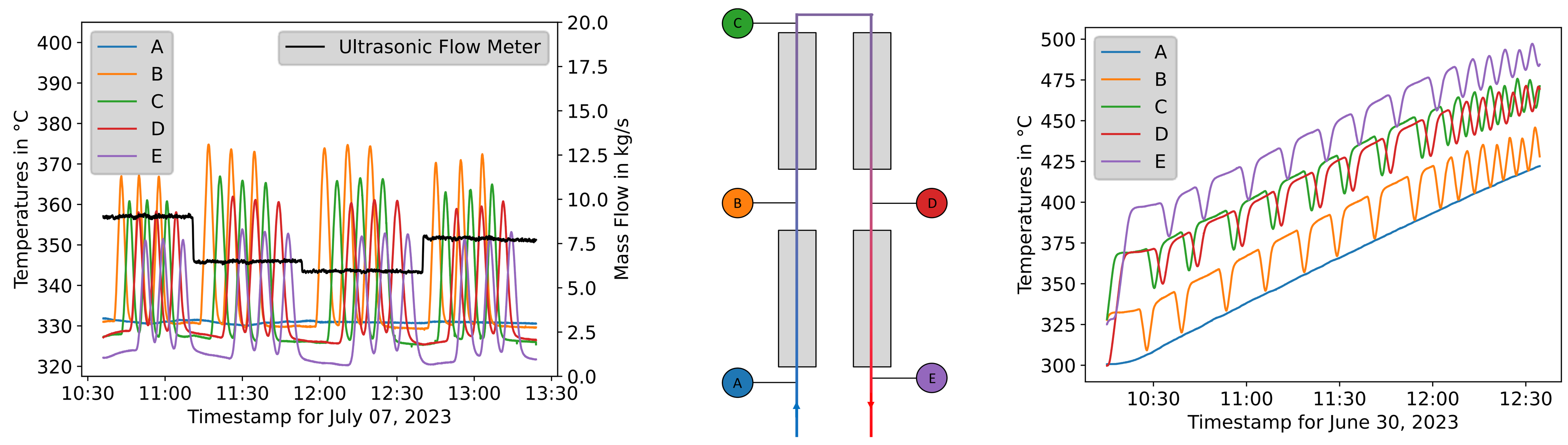

Fig. 2: Scheme of a PTC Loop with four SCAs and five temperature sensors (center). Corresponding temperatures for example measurements focusing SCA1 with varying mass flow (left) and measurements defocusing SCA1 with varying inlet temperature (right) of the research facility EMSP, see description below.

Peak-to-Peak Analysis vs. Cross-Correlation

While peak-to-peak analysis considers only the maxima and minima of the thermal step responses, cross-correlation examines the entire thermal step response to determine the time offset (Fig. 3) by a "best fit" shift of the entire curve.

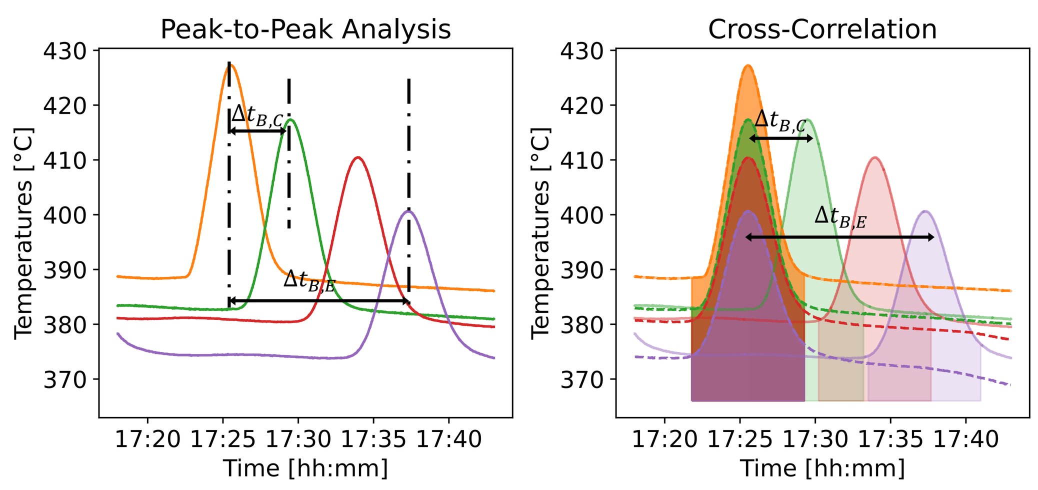

Fig. 3: Determination of time delay via peak-to-peak analysis (left) and cross-correlation (right) of a thermal step response.

Reference Plant and Dataset

Reference Plant

- Évora Molten Salt Platform (EMSP), a research facility located in Portugal (Fig.4) with a total electric power of 3.5 MW [5]
- Solar field composed of 4 solar collector assemblies (SCA) with parabolic trough collectors (PTC) - HTF is molten salt
- In total 36 solar collector elements (SCE), unevenly distributed (SCA 1&4 have 10 each and SCA 2&3 have 8 each)
- Direct 2-tank storage system operating with molten salt
- Steam generation and SCA3 were not operating during the conducted measurements

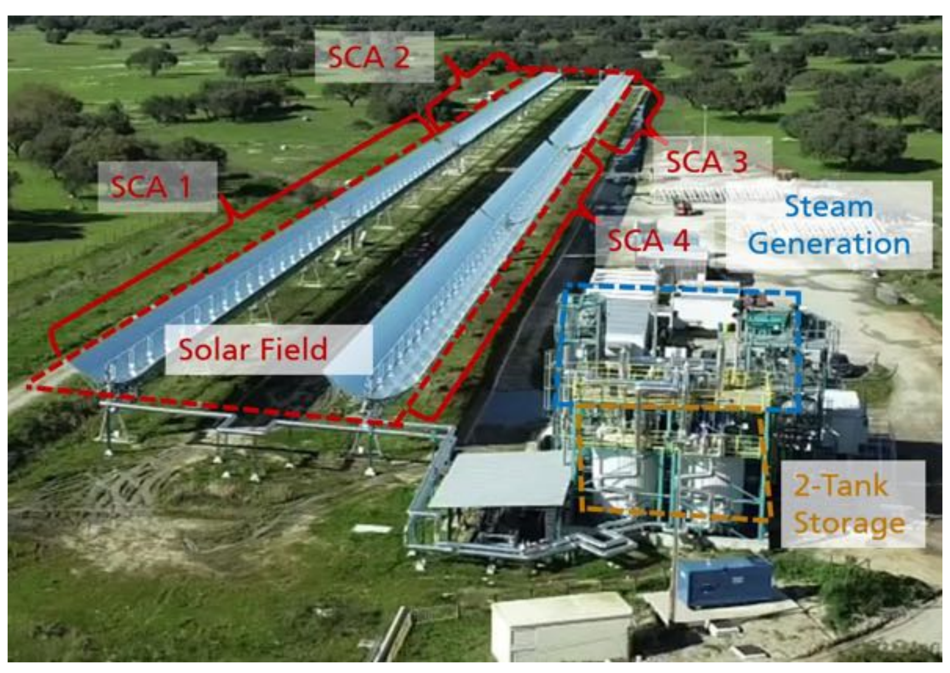

Fig. 4: Aerial view of EMSP highlighting the main components solar field, storage tank and steam generation [5].

Dataset

- More than 100 individual tests conducted between June 26th and July 07th 2024 moving collectors actively
- Wide range of different considered parameters including e.g., mass flow, inlet temperature & (de-)focusing time (Fig. 2)
- 24 additional peaks analyzed caused by passing clouds

Results

Peak-to-Peak Analysis vs. Cross-Correlation

- Evaluable step responses for a wide range of parameters
- Both the peak-to-peak analysis and the cross-correlation method show a linear relationship between measured and calculated mass flow (Fig. 5).
- Applying cross-correlation results in lower mean deviations of calculated vs. measured normalized mass flow (2.8%) compared to peak-to-peak analysis (3.8%) (Fig. 5 & 6,left)

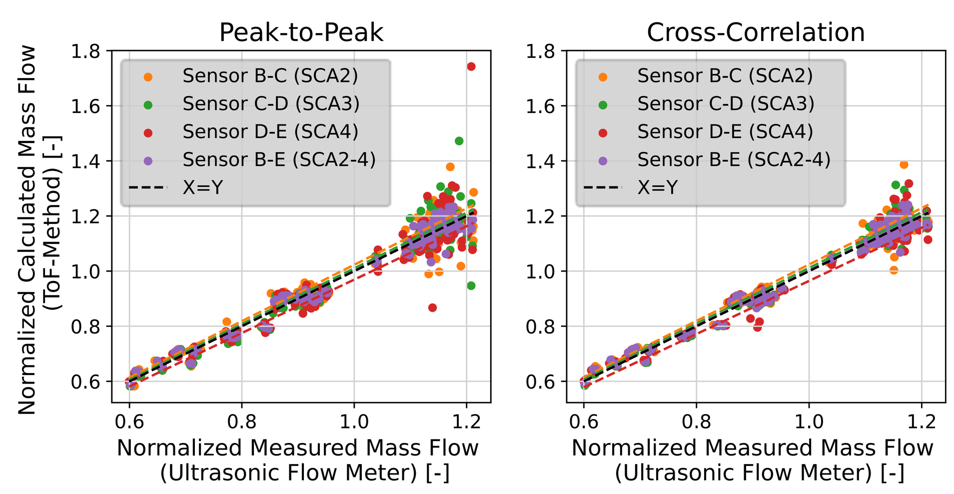

Fig. 5: Normalized calculated and measured mass flows at different positions for peak-to-peak analysis and cross-correlation (points) & linear fit curves (dotted lines).

Analysis of Passing Clouds

- Linear relationship of mass flows also for step responses due to clouds/ fluctuating direct normal irradiation (DNI)
- Deviation of normalized measurement and calculation <5%
- Deviation of mass flows is slightly higher for passing clouds compared to collector (de-) focusing (Fig. 6, right)

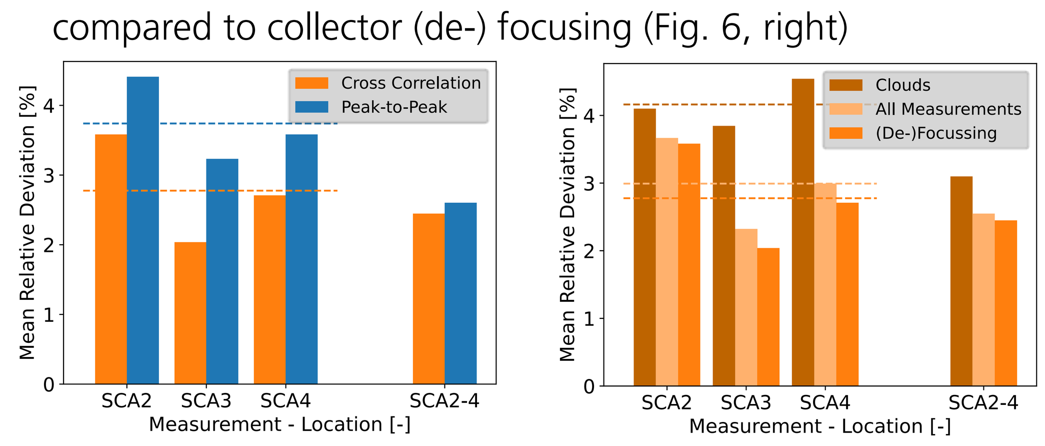

Fig. 6: Mean mass flow deviations for different methods of data analysis (left) and origins of step responses (right). Dashed lines represents mean deviation of three single positions SCA 2, 3 & 4

Conclusion and Outlook

The ToF method is applied to calculate mass flow distributions in solar fields of CSP plants. The smallest deviations (<3%) between measured and calculated normalized mass flow are achieved by briefly (de-)focusing the collectors using cross-correlation over long distances (3 SCAs). However, even with peak-to-peak analysis, fluctuating DNI of passing clouds or shorter distances (1 SCA), the mean deviation remains <5%. As the ToF method is **simple, safe, cost effective and non-invasive**, it has a high potential to increase solar field efficiency due to the detection of inefficient collectors and the possibility of improved maintenance.

[1] China Solar Thermal Alliance CSTA (2020): China Supcon Delingha 50 MW Concentrated Solar Power plant achieved record high performance in Feb. 2020. Available online at http://en.cnste.org/html/csp/2020/0228/645.html, checked on 07/04/2024
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[3] Kraft et al. (2023): Vacuum Loss Detection of PTC in CSP plants via Temperature-Sensors. Accepted in June 2024 in SolarPACES Conference Papers
[4] Kraft et al. (2024): Mass Flow Distribution Measurement in Concentrated Solar Power Plants via Thermal Time-of-Flight Method. In Solar Energy 273, p. 112486. DOI: 10.1016/j.solener.2024.112486.
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