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.

Using the ToF (Time-of-Flight) method, mass flow distribution measurement is enabled, which aims at measuring the time delay 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 and thus 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 (Concentrating 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.

**Mass Flow Calculation**

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

\[
\dot{m} = \frac{V}{\rho} = \frac{Q}{\Delta t} \cdot \frac{diameter}{ho \cdot \pi \cdot \text{length}}
\]

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

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

**Peak-to-Peak Analysis vs. Cross-Correlation**

While peak-to-peak analysis considers only the maximum and minimum 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.

**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 system operating with molten salt.
- Steam generation and SCA3 were not operating during the measured datasets.
- HTF is molten salt.

**Dataset**

- More than 100 individual tests conducted between June 26th and July 7th 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**
  - Evaluatable 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).

**Analysis of Passing Clouds**

- Linear relationship of mass flows also for step responses due to cloud fluctuating direct normal irradiation (DNI).
- Deviation of normalized measured and calculated mass flow is ±5%.
- Deviation of mass flows is slightly higher for passing clouds compared to collector (de-)focusing (Fig. 6).

**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 mass flow are achieved by briefly (de-)focusing the collectors using cross-correlation over long distances (3 SCA). 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.