SFERA-III

Solar Facilities for the European Research Area

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EU Project SFERA III Workshop:
Case studies on sensible heat storage

Julius Weiss, Fraunhofer ISE

JOINT RESEARCH ACTIVITIES

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Sensible thermal energy storages - fair evaluation What is the problem?

Considered as rather simple:

- **Something (most of the time a liquid or solid) is heated up or cooled down.**

If material properties are constant, energy stored (thermal power of storage) can be described by:

$E = m \cdot c \cdot \Delta T$

m = mass

c = specific thermal capacity

ΔT = Temperature difference

„...thermal capacity of 100 kWh." - Reasons for discrepancy in calculation:

- Missed to mention temperatures considered.
  Theoretical storage capacity for solar salt e.g.:
  - Maximum capacity: 290-550°C → 100 kWh
  - Rated conditions: (Dependent on the design of the plant). E.g 290-390°C if the upper temperature of the heat source is limited → 40.5 kWh
- Missed to mention if this is a theoretical value, only dependent on material properties, or a measured value
  → In experiments mass flow rates and temperatures are fluctuating, distribution is not perfect, heat loss,...
- Material properties are not constant!

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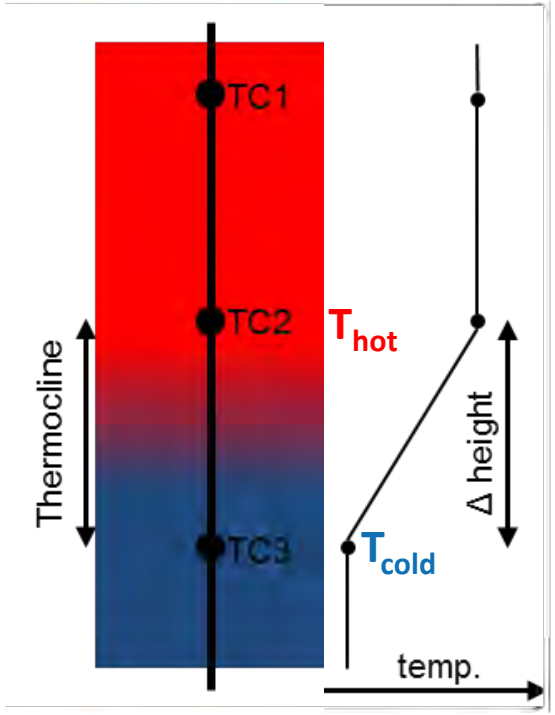
Sensible thermal energy storages - fair evaluation Selection of performance indicators

Measuring the thickness of the thermocline (qualitative evaluation method)

Temperature measured by the thermocouples gives indication about the separation of cold and hot fluid → Stratification

- Hard to evaluate experimentally
- Resolution limited to number of sensors inside the storage
- The indicator is useful for the analysis of a specific setup and to identify potential for optimization of this specific solution and setup
  (no transparent comparison to other setups is possible)

→For fair technical evaluation more generic criteria are needed



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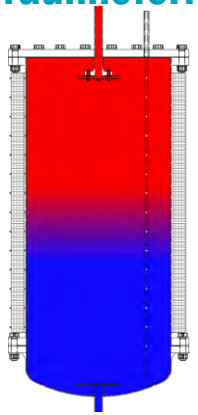
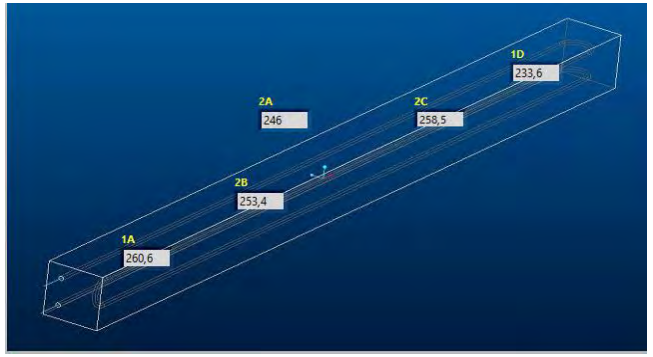
Sensible storages guidelines applied for so far

CEA: STONE-Facility

Fraunhofer: Molten salt loop



ENEA: Concrete module



Volume	2.4 m^3	0.4 m^3	0.12 m^3
HTF	Therminol 66	Solar salt	Paratherm NF
Volume of HTF	27%	100%	1.5%
Solid matrix	3 cm rock and 3 mm sand	-	Concrete
Temperatur	118-225 °C	290-390 °C	217-250 °C
Theoretical storage capacity	150 kWh	29 kWh	2.57 kWh

ISE- molten salt thermocline storage

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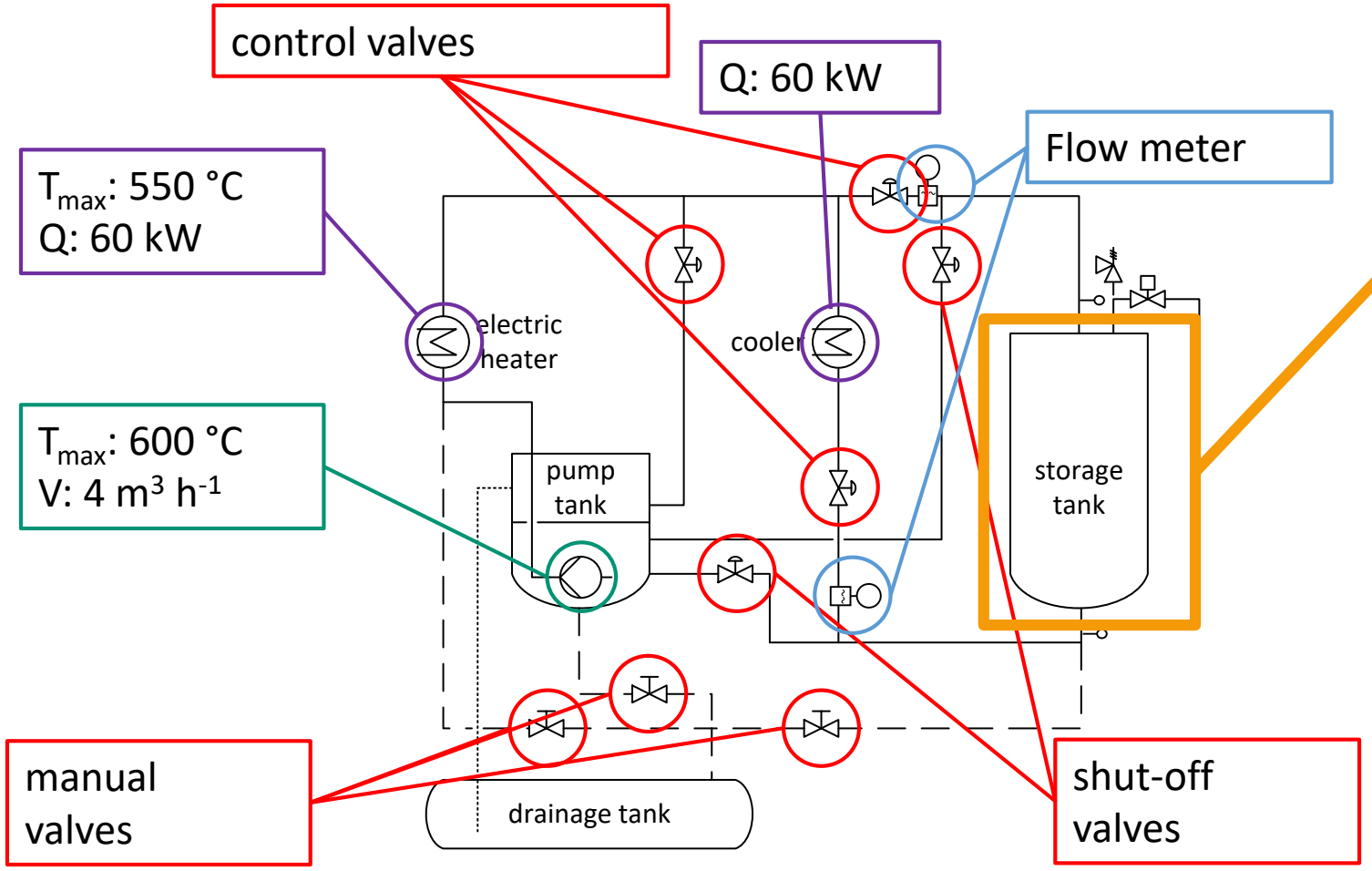
Operation



Operation requires:

- control of multiple actuators
- consideration of multiple sensors
  - →many data points

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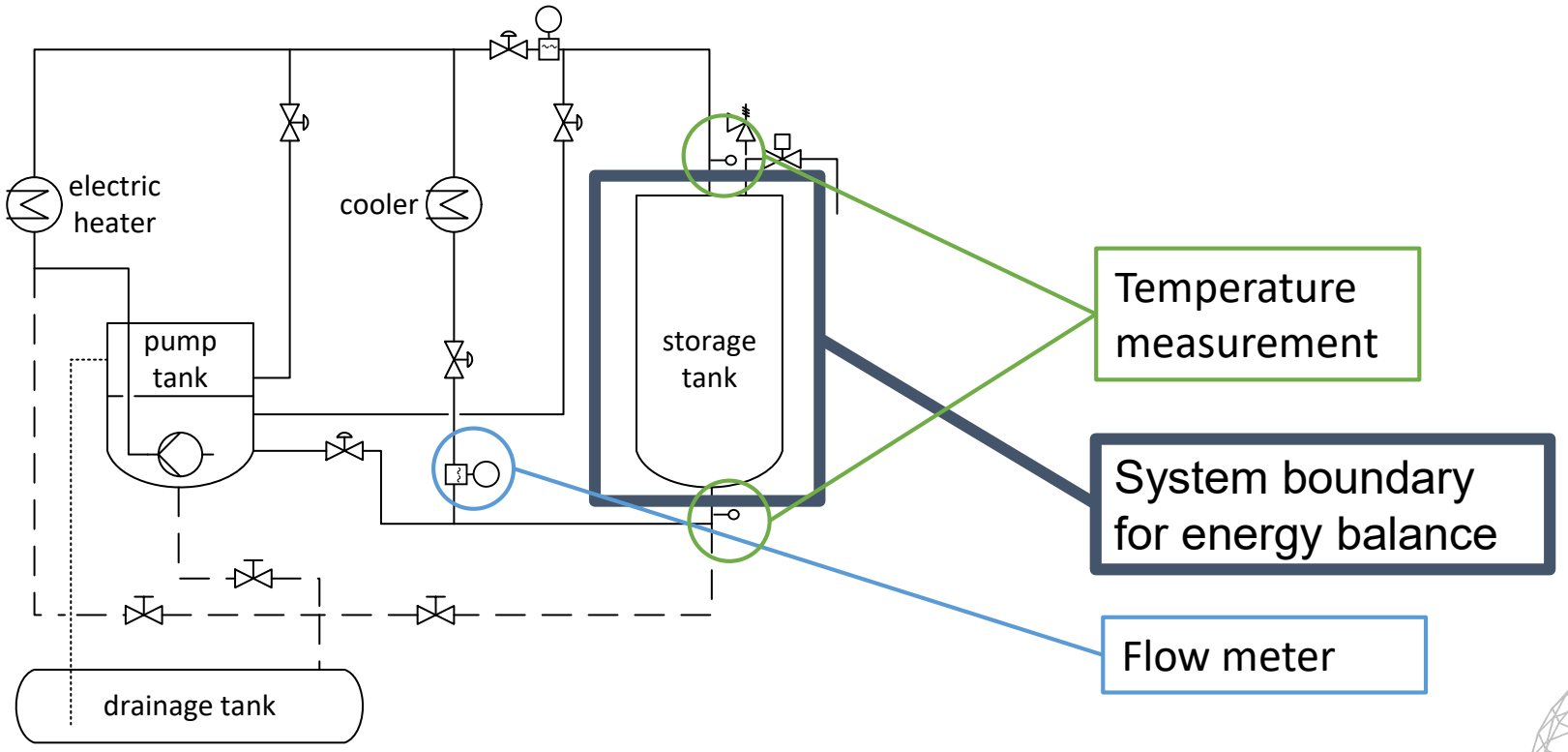
ISE- molten salt thermocline storage

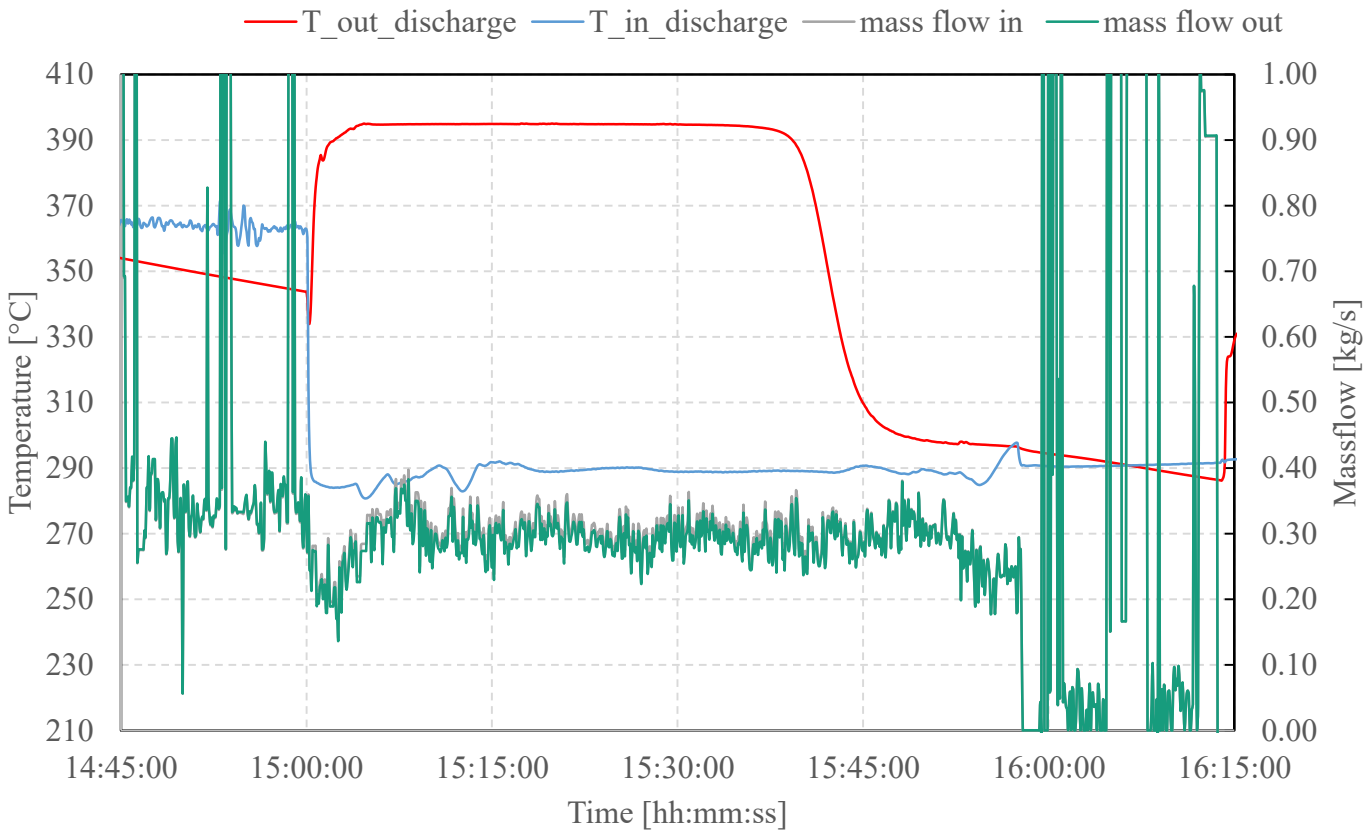
Evaluation of discharge

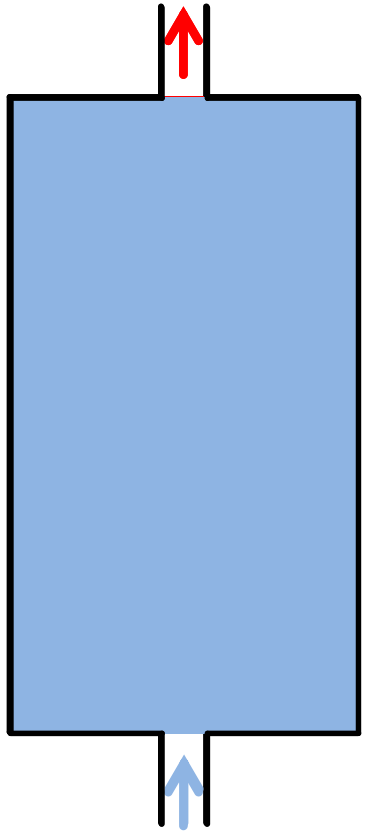
+ Temperature dependent material properties



ISE- molten salt thermocline storage

Evaluation of a single discharge

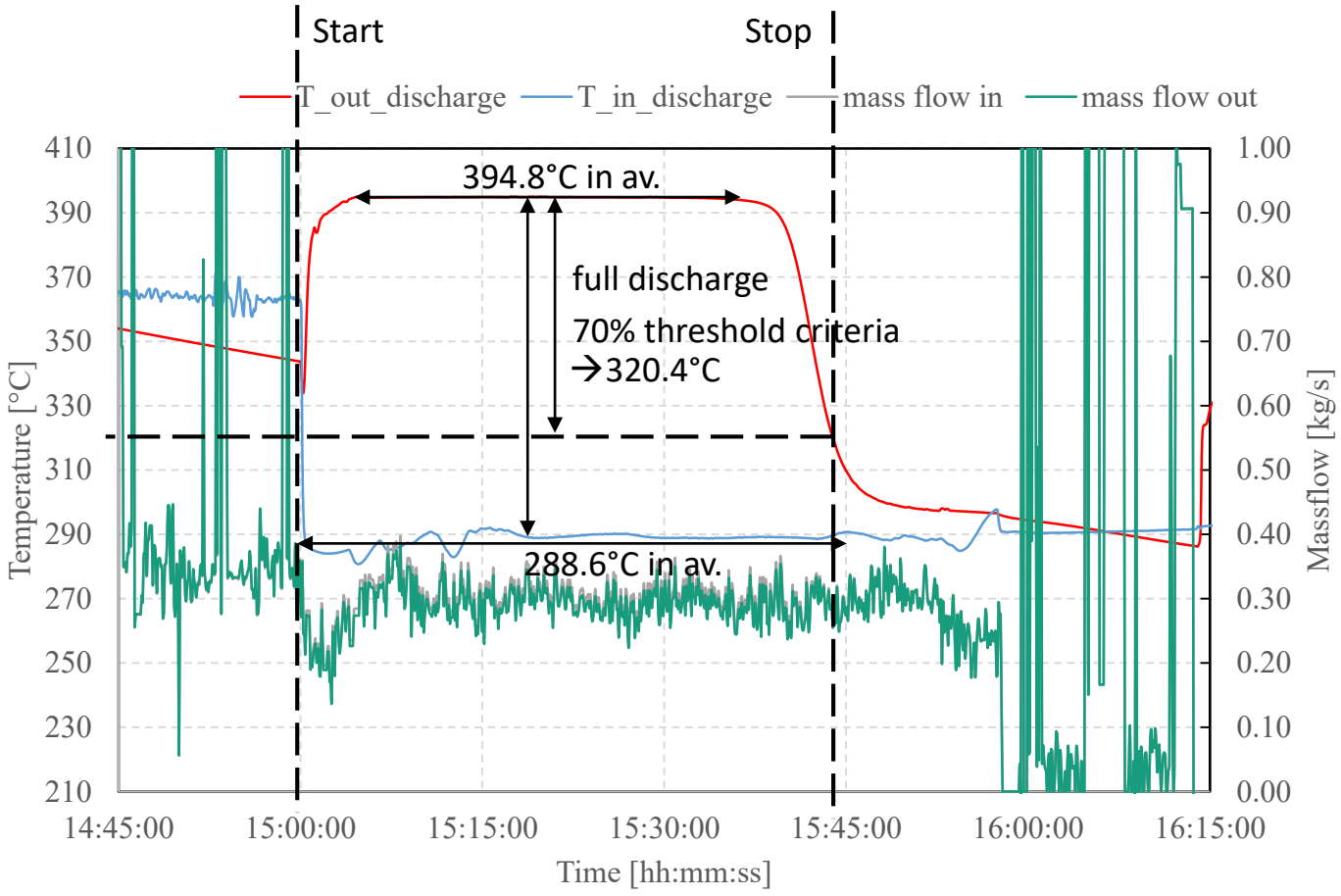




Cold molten salt

ISE- molten salt thermocline storage

Evaluation of a single discharge



Evaluation of utilization rate:

$$\text{Utilization rate} = \frac{SC\ (\text{Storage capacity})}{SC_{th}(\text{Theoretical } SC)}$$

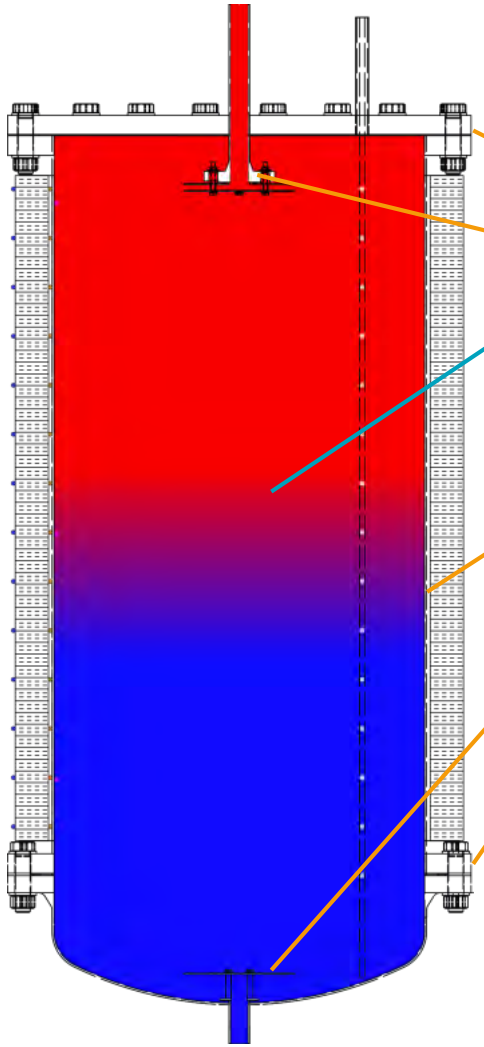
$$SC = \int_{t_{initial\ conditions}}^{t_{full\ discharge\ conditions}} (\dot{m}_{out}h_{out} - \dot{m}_{in}h_{in})dt \quad ?$$

$$= 28.9\ \text{kWh}$$

$$SC_{th} = V * \sum_{Materials} (\rho_{ch} * h_{ch} - \rho_{dch} * h_{dch})$$

Sensible thermal energy storages - fair evaluation

Evaluation of theoretical storage capacity



Volume of Salt 0,394 m^3

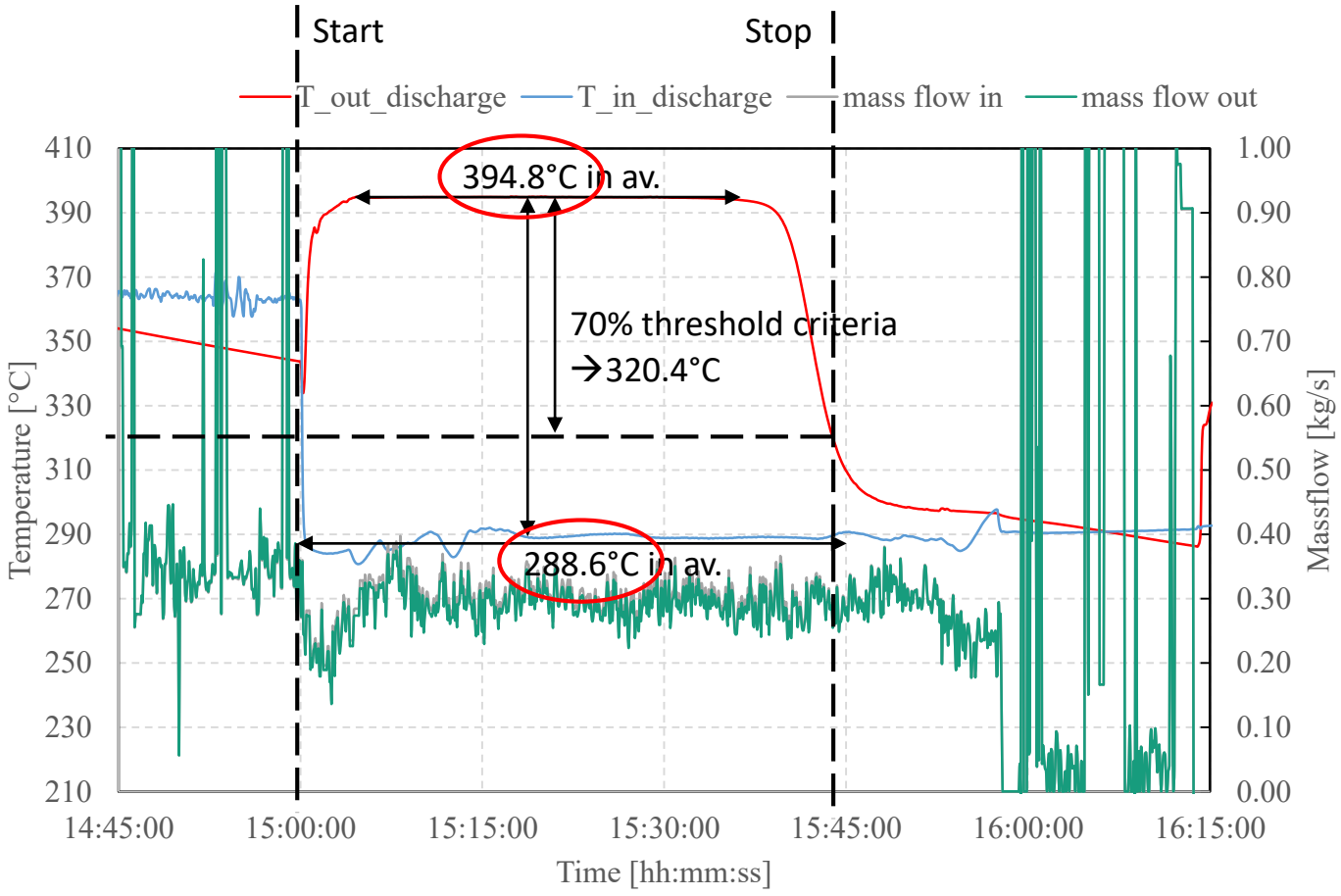
(including convex end)

Mass of steel 293,3 kg

- Not including thermal insulation

ISE- molten salt thermocline storage

Evaluation of a single discharge



Evaluation of utilization rate:

$$\text{Utilization rate} = \frac{SC\ (\text{Storage capacity})}{SC_{th}(\text{Theoretical } SC)}$$

$$SC = \int_{t_{initial\ conditions}}^{t_{full\ discharge\ conditions}} (\dot{m}_{out}h_{out} - \dot{m}_{in}h_{in})dt$$

$$= 28.9 \text{ kWh}$$

$$SC_{th} = V * \sum_{Materials} (\rho_{ch} * h_{ch} - \rho_{dch} * h_{dch}) \quad @\ rated\ conditions$$

$$= 33.3 \text{ kWh (87\% salt and 13\% Steel)}$$

$$\rightarrow \text{Utilization rate} = 86.9\ \%$$

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Sensible thermal energy storages - fair evaluation

Take away message

For fair and reproducible evaluation consent on calculation procedure and definitions is required.

Besides this:

- Clear statement what has been considered as “rated conditions” (Not obvious as temperature in experimental conditions is not constant)
- Clear statement on definition of period of time that was evaluated and why (relevant valve control for operation modes, threshold temperatures, etc.)
- Provide the properties as used for the calculation (e.g. directly give temperature dependent enthalpy and not the thermal capacity, that needs to be integrated)

THANK YOU FOR YOUR ATTENTION!
ANY QUESTIONS?