Institute of Engineering
Engineering Thermodynamics

Experimental and Numerical Investigation of a 4 MWh Single-Tank Thermocline Storage

Christian Odenthal, Freerk Klasing and Thomas Bauer

Introduction

For large scale thermal energy storage at temperatures above 300°C, two-tank molten salt systems mark the current state-of-the-art. The two-tank concept offers significant cost reduction potential by storing the salt inside a single tank thermocline (TC), as indicated in Fig. 1. Through this first step, costs for pumps, the unused storage volume and land consumption are reduced. The separation of both phases is achieved by stratification due to density variations. In more advanced concepts (2nd step) a moving barrier (TCMB) could also be applied. Since salt costs can be as high as half of the total costs [1], further potential for cost reductions is given [2]: a large fraction of the molten salt can be substituted by a cheap solid material as in the thermocline with filler concept (TCF).

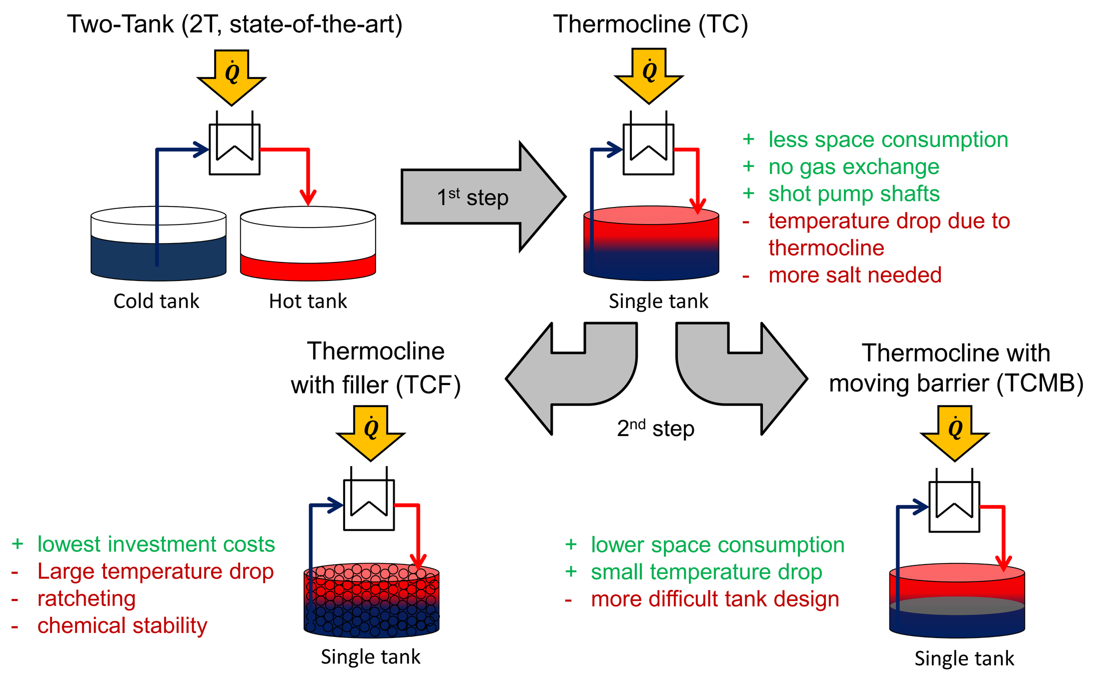

Fig. 1: Two-Tank storage system and possible concepts for improvements

TESIS:store facility

The "test facility for thermal energy storage in molten salts" (TESIS:store) is located at DLR in Cologne, Germany, see Fig. 2. The plant is ready for testing all of the aforementioned kinds of storage concepts.

Fig. 2: The TESIS test facility in Cologne

The storage volume has a length of 5.4 m with a total tank volume of 22 m³. The plant allows the investigation of the thermocline concept with and without filler and gaining widespread operation experience. Heat tracing along the containment walls and the piping ensures adiabatic conditions. Operational parameters of the plant are summarized in Table 1.

Table 1: Operational parameters TESIS:store

Salt mass	40 + 45 metric tons
Molten salt	nitrate / nitrite salts
Temperature range	150 to 560 °C
Capacity (ΔT=250K)	~ 200 kWh/m³
Heating / cooling power	115+100 / 420 kW
Mass flow rate	max. 4 kg/s

Current test setup: Thermocline (TC)

As HTF a binary mixture of 60 % $NaNO_3$ and 40 % KNO_3 (Solar Salt) at maximum temperature is used in the plant for several consecutive charging and discharging cycles. The storage volume is equipped with 150 thermocouples along the mid axis and additionally at four planes in two radial directions each, as shown in Fig. 3

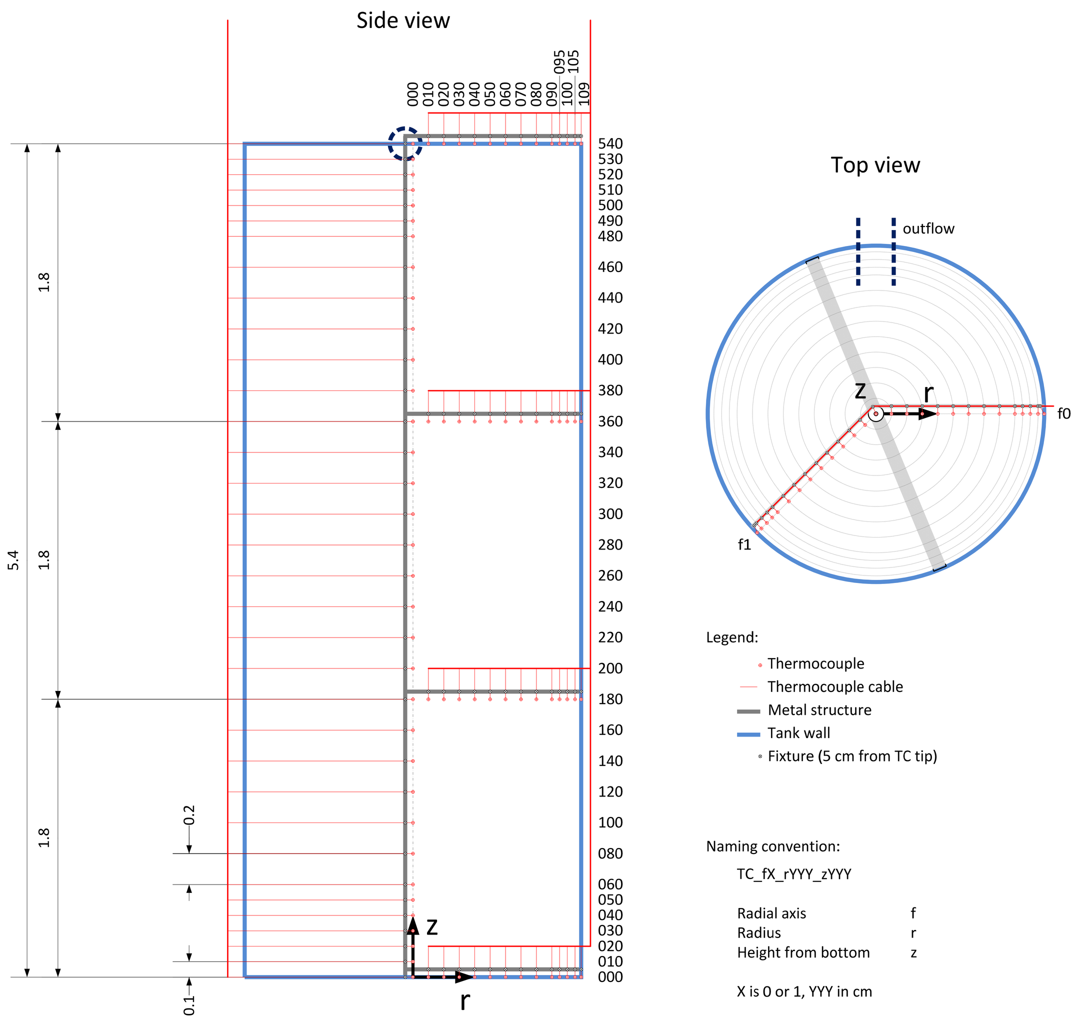

Fig. 3: Thermocouple positions of the storage tank

Numerical model

An implicit 1D single phase numerical model is implemented in Matlab®. The model divides the storage volume into several layers of uniform temperature T_f. The change of inner energy inside the layer is governed by the convective and conductive flux in and out of the layer. The resulting differential equation simplifies to:

$$\frac{\partial T_\mathrm{f}}{\partial t} = -v_{0,\mathrm{x,f}} \frac{\partial T_\mathrm{f}}{\partial x} + \frac{\lambda_\mathrm{f}}{\rho_\mathrm{f} c_{\mathrm{p,f}}} \frac{\partial^2 T_\mathrm{f}}{\partial x^2}$$

Experimental results

The radial temperature profiles at the beginning and the end of the charging cycle are shown in Fig. 4. Several thermocouples are damaged due to improper installation. However, all remaining thermocouples show a stable temperature distribution along the radial axis, indicating a uniform flow pattern (plug flow). At the beginning of the charging cycle, the fluid level is at 5.35 m due to the lateral outflow (see Fig. 3). Thus, the upper thermo-couples are not wetted, resulting in larger discrepancies.

The resulting axial temperature profiles at different times during the charge cycle are shown in Fig. 5. As can be seen, a stable thermocline profile is developed, which extends over less than one meter.

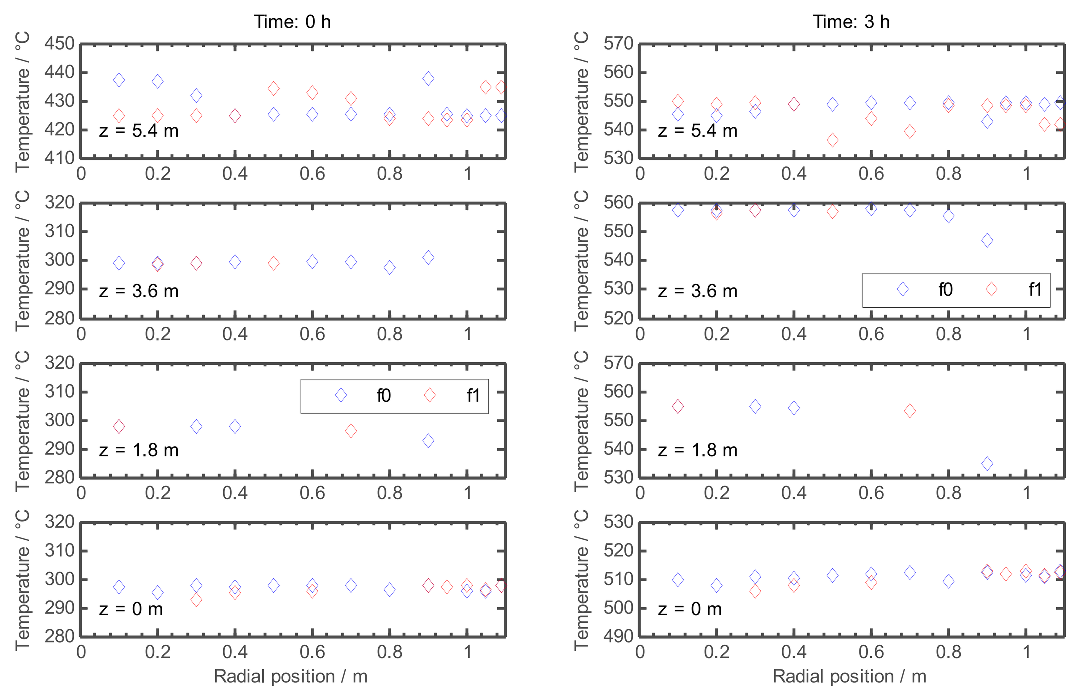

Fig. 4: Measured radial temperature profiles at the beginning and end of charging

Model comparison

The measured inlet temperature and mass flow were taken as inlet conditions and the actual temperature profile at the beginning as initial condition for the simulations. The model also shows a good overall agreement with the experiments, shown also in Fig. 5. Some discrepancies at the end of the discharge cycle are probably caused by mixing in the inlet region.

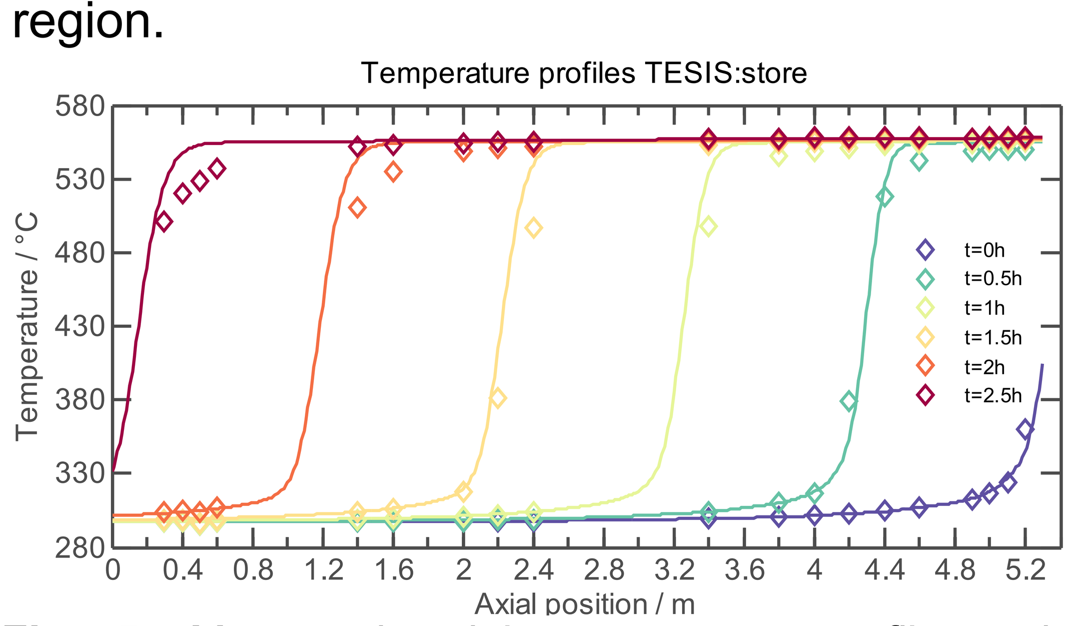

Fig. 5: Measured axial temperature profile and simulation results

Conclusion

- A stable thermocline can be established
- Experimental data in a relevant size for model validation has been acquired
- Good agreement with numerical model

Literature

[1] U. Herrmann, B. Kelly, and H. Price, "Two-tank molten salt storage for parabolic trough solar power plants," *Energy*, vol. 29, no. 5–6, pp. 883–893, 2004,

[2] F. Klasing, C. Odenthal, B. Trost, T. Hirsch, and T. Bauer, "Techno-Economic Assessment for Large Scale Thermocline Filler TES Systems in a Molten Salt Parabolic Trough Plant," 2017.

Knowledge for Tomorrow

Wissen für Morgen

DLR Deutsches Zentrum für Luft- und Raumfahrt

Funded in the MS-STORE project (contract No. 0325497 A) by the German Federal Ministry for Economic Affairs and Energy