Hessisches Kompetenzzentrum
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High-Resolution CFD Modeling of a Large-Scale Short-Term Thermal Energy Storage Unit

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Clusters
Lichtenberg II Cluster Darmstadt

Software
COMSOL

Institute
Institute for Technical Thermodynamics

University
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Introduction

With the increasing use of renewable energy comes an increasing volatility in energy supply due to external factors. Thus, energy storage, including thermal energy storage, is essential to allow for more flexibility. This project studies the behavior of a large short-scale thermal energy storage system as employed by ENTEGA AG at the waste incineration plant in Darmstadt. The developed CFD model is validated using measurement data from the storage and used to study the influence of various parameters on storage performance.

Methods

The FEM software COMSOL Multiphysics is used to investigate the nonisothermal fluid flow inside the thermal energy storage and the heat transfer between fluid regions of different temperature as well as the entire storage and the environment. The storage is represented using a 2D-axisymmetric model, reducing computational effort compared to a full 3D model. For each investigated scenario, the initial temperature distribution and inflow boundary condition are taken from measurement data, thus enabling comparison with the behavior of the real storage system.

Results

In this phase of the project, the focus was on studying the influence of various parameters on storage performance by

varying them within a reasonable range and comparing them to the baseline storage system. The parameters studied at this point are the duration and intensity of charging and discharging, the storage aspect ratio, the storage insulation thickness and the operational temperatures of the storage system.
For charging and discharging, three different speeds and thus durations of charging were investigated. The enthalpy added to the storages was therefore constant across all variations. The results showed no disturbances of the thermocline regardless of charging speed and only minor differences in losses. This shows that the radial diffusers used in the storage are sufficiently large to provide smooth charging and discharging over a variety of charging speeds, even double that of typical charging speeds found in the measurement data.
The storage aspect ratio was studied in depth and the results presented at the Eurotherm Seminar in Lleida, Spain in May 2023. Five different aspect ratios, ranging from unity to four were investigated. Results show rising heat loss with increasing aspect ratio, as the surface to volume ratio increases. The relation was found to be directly proportional, meaning that there does not seem to be a significant change in the heat transfer coefficient between storage wall and fluid. Stratification seems to improve with increasing aspect ratio, as the simulations of an aspect ratio of three and four showed better resilience to small temperature inversions introduced into the storage during charging and also a slower relative growth of the thermocline thickness during general operation.
Energy and exergy losses during standby were both shown to be directly related to the insulation thickness. The reduction in losses with increasing insulation thickness is directly in line with the expected behavior from a calculation of the radial thermal resistance.
The investigated operational temperatures of the storage show an effect mostly on heat loss, with higher operating temperatures leading to higher heat loss than lower temperatures. However, the effect is not very pronounced when compared with the overall storage capacity of the system.

Discussion

Key parameters for thermal energy storages have been investigated and their influence on system performance modeled. This allows to design and operate efficient storage systems according to the needs of the respective district heating network.

Publications

Krüger, B.; Dammel, F.; Stephan, P., Investigating the Influence of the Aspect Ratio on the Exergetic Performance of a Large Thermal Energy Storage System using a High-Resolution CFD model, Eurotherm Seminar #116 “Innovative solutions for thermal energy storage deployment”, Lleida, Spain, 24.-26.05. (2023) https://doi.org/10.21001/eurotherm.seminar.116.2023

Krüger, B.; Dammel, F.; Stephan, P., Modeling a large thermal energy storage system using RANS turbulence models and high-resolution measurement data, Proceedings of the 8th World Congress on Mechanical, Chemical and Material Engineering MCM’22), Prague, Czech Republic, 31.07.-02.08 (2022) https://doi.org/10.11159/htff22.157

Reference

Krüger, B.; Dammel, F.; Stephan, P., High-Resolution CFD Modeling of a Large-Scale Short-Term Thermal Energy Storage Unit, Comsol Conference 2019, Cambridge, United Kingdom, 24.-26.09.2019

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