CFD-based analysis and minimization of mixing during the charging phase of a thermal energy storage tank

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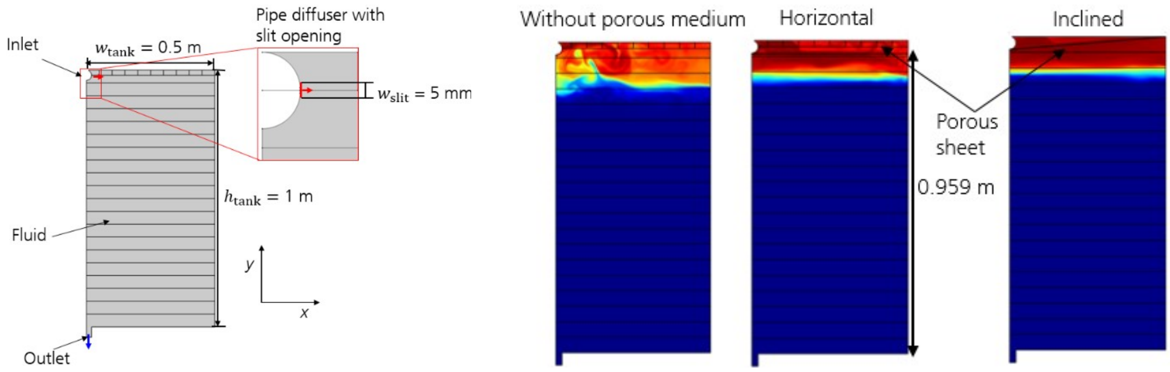
Electric power generation from renewable sources is heavily reliant on weather conditions, leading to fluctuations in the production. In addition to electric power, also domestic heat networks need to be considered as they directly supply and distribute energy in the form of heat. These networks may encounter less fluctuations on the side of production than on the side of the diurnally varying heat demand due to the consumers. Both types of fluctuations require storage facilities beyond the capacity of the grid itself. Thermal energy storage is a valuable solution in order to address this need by storing thermal energy during low-demand periods and release of the same during peak hours. This applies to both of the energy grids mentioned above where the primary goal is to operate on a moderate time horizon with the main purpose to supply energy in the from of heat.

This study focuses on the storage of sensible heat within a thermal energy storage tank as sketched in Fig. 1(a). Water is used as a storage medium as it offers a high heat capacity and is already used in domestic heating applications. The charging and discharging of the tank involves intricate fluid dynamical processes, and the exchange of water to optimize the exergy content. In order to minimize the losses, it is crucial to control the charging and the involved fluid dynamical mixing processes. This is not just task of suppressing fluid motions. By contrast, the goal and challenge is to inhibit mixing across the interface that separates the lower cool from the upper warm temperature zone in the tank as shown in Fig. 1(b). This interfacial layer, the so-called thermocline, is a fluid dynamical feature of density-stratified flows. Here it is as a result of the temperature difference and needs to be maintained during the charging (and discharging) phase. High-fidelity numerical approaches are needed to capture this feature. The goal of this study is to quantify which methods help to preserve a thin thermocline thickness during the first three quarters of the charging phase of the tank.

Transient numerical simulations are performed for a cuboidal storage tank (see Fig. 1) in order to resolve the transient features of the charging phase in a feasible manner. A diffuser is utilized for the inflow of water in order avoid large-scale overturning fluid motions in order to establish a thermal stratification. It is demonstrated that the thermal stratification can be furrther enhanced by introducing a layer of a porous medium at the top of the storage tank based on computational fluid dynamics (CFD) simulations using COMSOL Multiphysics®. Initially, a storage tank configuration without a porous medium is simulated in order to establish a baseline understanding. Subsequent simulations are performed systematically varying various parameters of the porous medium, such as porosity, location, and inclination. The inclined placement of the porous sheet yields a reduction of the thermocline thickness by approximately 38% compared to the reference case, thereby significantly enhancing the thermal stratification. As next step, the results obtained will be verified in an experimental apparatus at Fraunhofer ISE.

In the talk, the set-up of the numerical model, including the treatment of the porous sheet, the thermocline evolution together with the governing fluid flow, and the effect of an additionally installed porous sheet will be discussed.



(a) (b)

Figure 1. (a) Configuration of the thermal energy storage tank with a circular inlet diffuser. (b) Simulated instantaneous temperature field in an early stage of the charging process. CFD results shown represent the reference case without a porous medium, an intermediate case with a horizontal porous sheet, and the optimal case with an inclined porous sheet.