Flow structures in a stratified water thermal storage tank caused by a thermally conductive side wall

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Extended Abstract

Storing of thermal energy has an outstanding importance especially in combination of so-called "Carnot" and "Brayton" batteries and solar thermal power stations [1]. The main part of a thermal energy storage (TES) is a large tank filled with a hot working fluid. In order to achieve a high thermal efficiency high-temperature fluids like molten salts are used. Because of similar physical properties, model experiments in water are suitable. Water TES are also used for seasonal hot water storages in homes.

The best storage efficiency for both molten salt and hot water is achieved with good thermal stratification, i. e. hot and cold water are separated by a thin layer with a rapid temperature change, called thermocline. The working fluid supply system and the walls of the storage tank are sources for undesirable mixing and convective flow, which disturb the thermal stratification and thus reduce the thermal efficiency of the TES.

In a laboratory model experiment, a thermal stratification is generated inside a rectangular polycarbonate tank (375 mm × 375 mm × 750 mm) to investigate the temperature and velocity field using thermocouples and Particle Image Velocimetry (PIV)(Fig.1). One side wall of the tank is made of aluminum in order to study the influence of heat conduction through the wall. The heat flux in the aluminum wall leads to a warming of the lower part and a cooling of the upper part of the storage tank where the cold water and warm water is located, respectively. The reason for this is the low thermal conductivity of water compared to the metal wall.

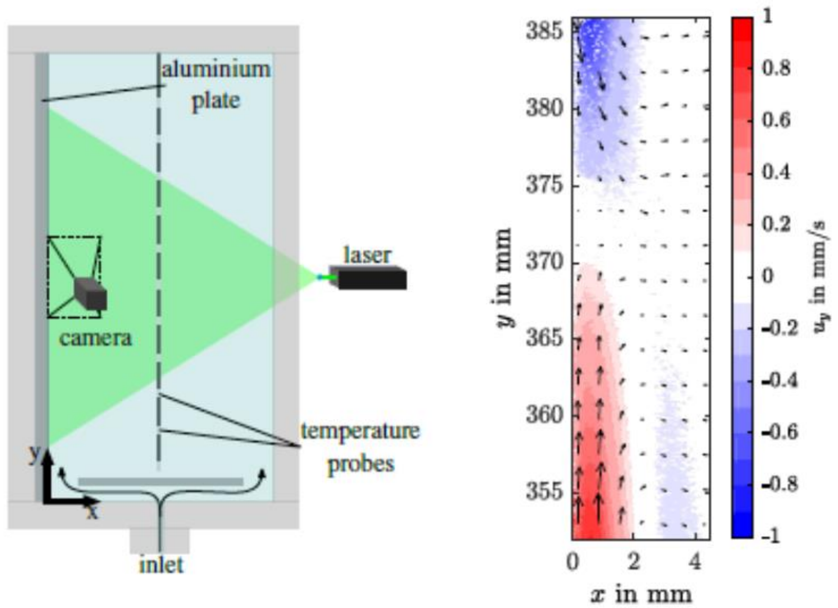

Fig. 1 Experimental setup for the PIV investigation of thermal convection in stratified TES near to a wall with strong thermal diffusivity (left). PIV measurement of the downward and upward convective flows near the aluminum wall (x = 0 mm) at half the tank height (y = 375 mm). The contour plot shows the y-component of the velocity and thus the two approaching vertical streams while the vector arrows show their redirection to the bulk area. The measurement has started after the completion of filling the tank. The image shows correlation of 98 double frames with a time difference of Δt = 0.4 s at a total time span of 20 s and at a spatial resolution of 6 x 6 px^2 (right).

PIV measurements show a vertical convective flow parallel to the aluminum wall, which spreads into the bulk region, leading to a complex 3d flow in the whole storage tank. More detailed PIV investigations demonstrate an additional shear layer near the thermally conducting wall and spatial flow instabilities in the horizontal transition layer at the half height of the tank along the interface between cold and hot water.

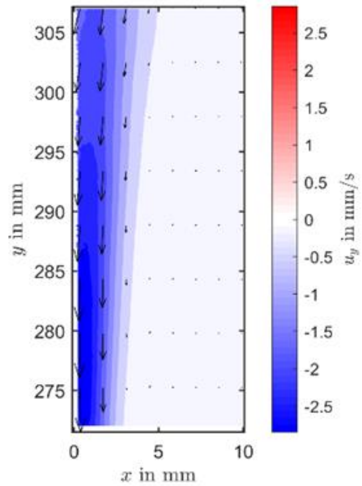

Fig. 2 PIV results of the velocity field close to the conducting wall in the upper part of the stratified TES.

For high-resolution boundary layer measurements very close to the aluminum wall, a 2d Laser Doppler Velocimeter (LDV) was applied. As results, mean velocity profiles and higher statistical moment are used to analyze the properties of the near-wall flow and its influence to the unwanted local mixing of stratification.

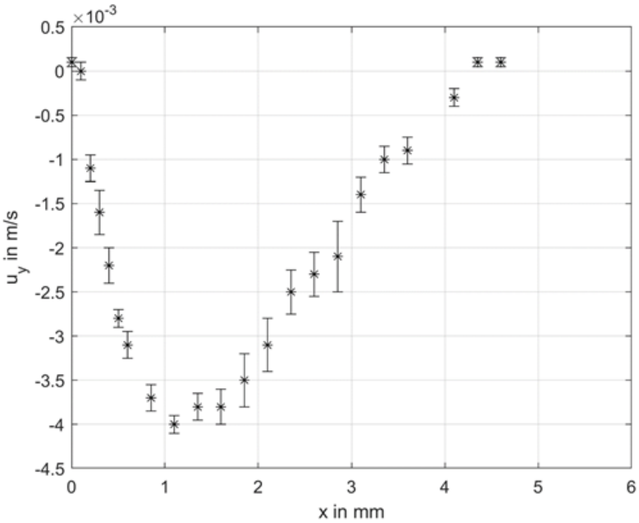

Fig. 3: LDV results: boundary layer profile at the aluminum wall at y = 495 mm. The velocity data are averaged over 100 burst.

Figure 3 shows the velocity profile (vertical component) in the boundary layer at the upper part of the aluminum wall. The boundary layer thickness agree very well with the PIV results (Fig. 2) but the magnitude of the wall-parallel velocity grows up to 4 mm/s. This value is higher in comparison to the PIV data, resulting from different initial temperatures of the thermal stratification and different start times of the LDV measurments. In future, a new water supply and heating system will ensure reproducible initial conditions of the thermal stratification for a more detailed study of the mixing process with PIV and LDV.

References

[1] R. B. Laughlin R B (2017) Pumped thermal grid storage with heat exchange, J. Renewable and Sustainable Energy, 9, 044103