Numerical Simulation of the Effect of Inlet Design on Thermal Storage Tank Performance Using COMSOL Multiphysics®

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Abstract

Introduction: Thermal stratification of solar thermal energy systems in hot water tanks has a significant positive effect on their efficiency. Solar hot water tanks, which keep the hot and cold water separated by means of gravitational stratification are widely used for load management and energy conservation applications. The single stratified tank is attractive in low to medium temperature applications, due to its simplicity and low cost. Despite diverse research efforts made so far, the optimum design and the effects of geometrical and operating parameters on the performance of thermal storage systems has only been partially undertaken, making design engineers rely significantly on simple numerical tools. In the present study, the inlet configuration influence on the stratification performance for the thermal energy storage tanks is simulated, using the COMSOL Multiphysics software package. A 3D unsteady CFD model has been developed and validated. Effects of placing a flat baffle plate at the inlet of a solar storage tank on stratification performance was studied. The influence of the inlet jet position with and without plate and for a tank with conventional wall side ports without plate, on the preservation and enhancement of the thermal stratification was investigated.

Use of COMSOL Multiphysics/CFD: Figure 1 illustrates the geometric models of the solar hot water storage tanks for the discharge process. 3D unsteady flow models were built in the CFD commercial software COMSOL. The unsteady simulations were run for a time period, which corresponds to the time required to replace the entire tank of fluid if no mixing was involved. This corresponds to a residence time of 4230 s and a time step of 0.5 s, which was considered to be acceptable in terms of accuracy and efficiency.

Results: Effects of placing a flat baffle plate at the inlet of the incoming fluid on the thermal stratification within the tank was examined. The discharge cycle was simulated with tank water to be initially at a uniform temperature of 45oC, the inlet cold water at a temperature of 20oC, from the bottom of the solar storage tank. The models were run for a mass flow rate of 0.15 kg/s. Figure 2 and Figure 3 show the simulated distribution of the dimensionless hot water temperature on the mid-plane of the water tank at two different time levels of 500 s and 1500 s, respectively. As can be seen, almost a stable thermal stratification is maintained for the case with the tank with a plate, which modified the temperature and velocity flow fields at the inlet jet, allowing a better stratification compared to the tanks without plate or with side wall inlet/outlet ports.

Conclusion: This study presented the results of 3D unsteady CFD simulations to investigate the influence of adding a flat baffle plate at the entrance during the discharging operation on the flow behaviour, thermal stratification, and performance of a hot water storage tank installed in solar thermal energy systems. The CFD results showed that the plate modified the flow field close to the inlet jet, allowing stratification enhancement, compared to a tank without plate or a tank with side wall ports near the tank bottom/top surfaces.
The 3D COMSOL CFD model may serve as a valuable design tool for future optimization of solar thermally stratified energy storage tanks.

Reference

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Figures used in the abstract

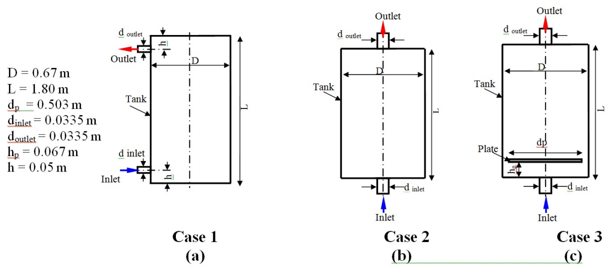

Figure 1: Schematic of the centre plane of the thermal storage tank geometry with: (a) side wall ports, without plate; (b) centre ports, without plate; (b) centre ports, with plate.

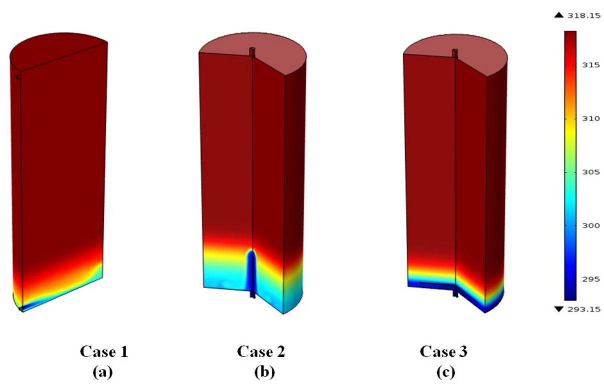

Figure 2: Comparison of centreline dimensionless temperature along the tank height at t = 500 s; mass flow rate = 0.15 kg/s for: (a) case 1; (b) case 2; (c) case 3.

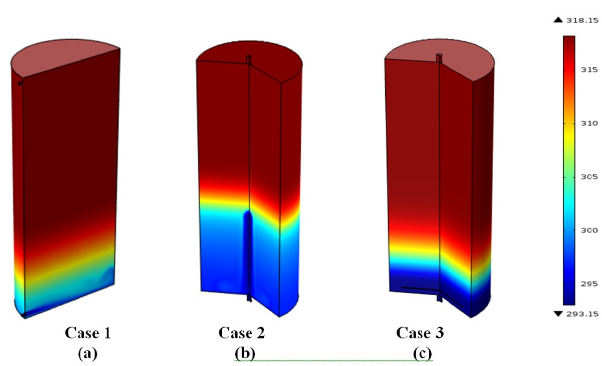

Figure 3: Comparison of centreline dimensionless temperature along the tank height at t = 1500 s; mass flow rate = 0.15 kg/s for: (a) case 1; (b) case 2; (c) case 3.