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COMSOL CONFERENCE BOSTON 2013

Numerical Simulation of the Effect of Inlet Design on Thermal Storage Tank Performance Using CFD

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Introduction

Thermal stratification in hot water tanks of solar thermal energy systems has a significant positive effect on their efficiency. Solar hot water tanks, which keep the hot and cold water 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.

In the present study, the inlet configuration influence on the stratification performance for thermal energy storage tanks is simulated, using COMSOL 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.

Model Geometry and Set-up

Fig. 1 illustrates the geometric models of the solar hot water storage tanks for 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.

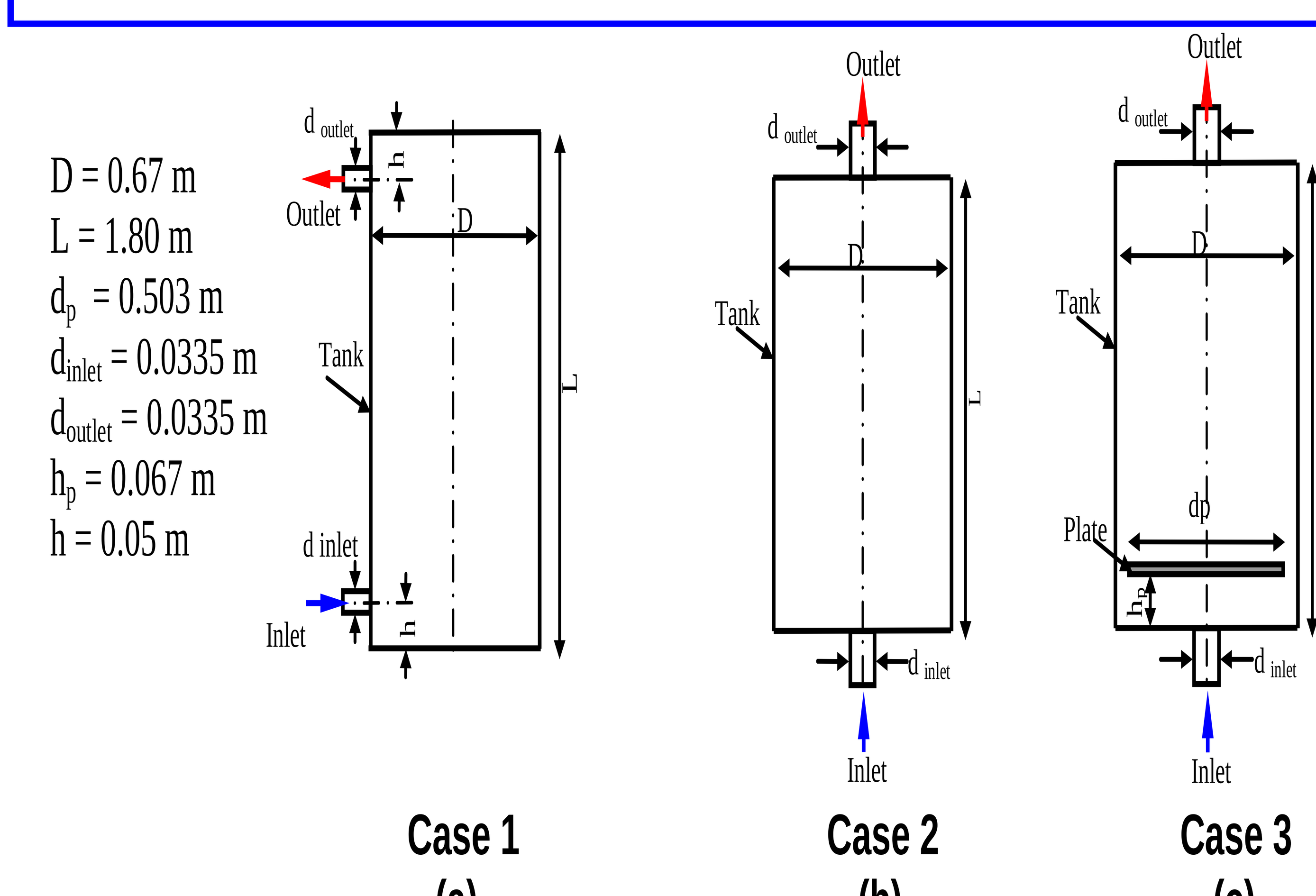

Figure 1. Schematic of the centre plane of the thermal storage tank geometry with: (a) side wall ports, without plate; (b) centre ports, without plate; (b) centre ports, with plate.

The Navier-Stokes and energy equations in three-dimensional form were used to solve for the transient hydrodynamic and thermal fields. Therefore, the resulting governing equations with consideration of gravity effect can be written as follows:

Conservation of mass:

$$\nabla \cdot u = 0$$

Conservation of momentum:

$$\rho \frac{\partial u}{\partial t} + (\rho u \cdot \nabla) u = -\nabla p + \nabla \cdot \tau - \rho \beta (T - T_{ref}) g$$

The conjugate heat transfer and laminar flow is used to model slow-moving flow (Re = 1440-5765) in the thermal storage tank where temperature and energy transport are coupled.

The above Equations are solved together with an energy balance in unsteady 3D.

Conservation of energy:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k \nabla T)$$

Simulation 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 20 ºC, 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 1500 s and 3600 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.

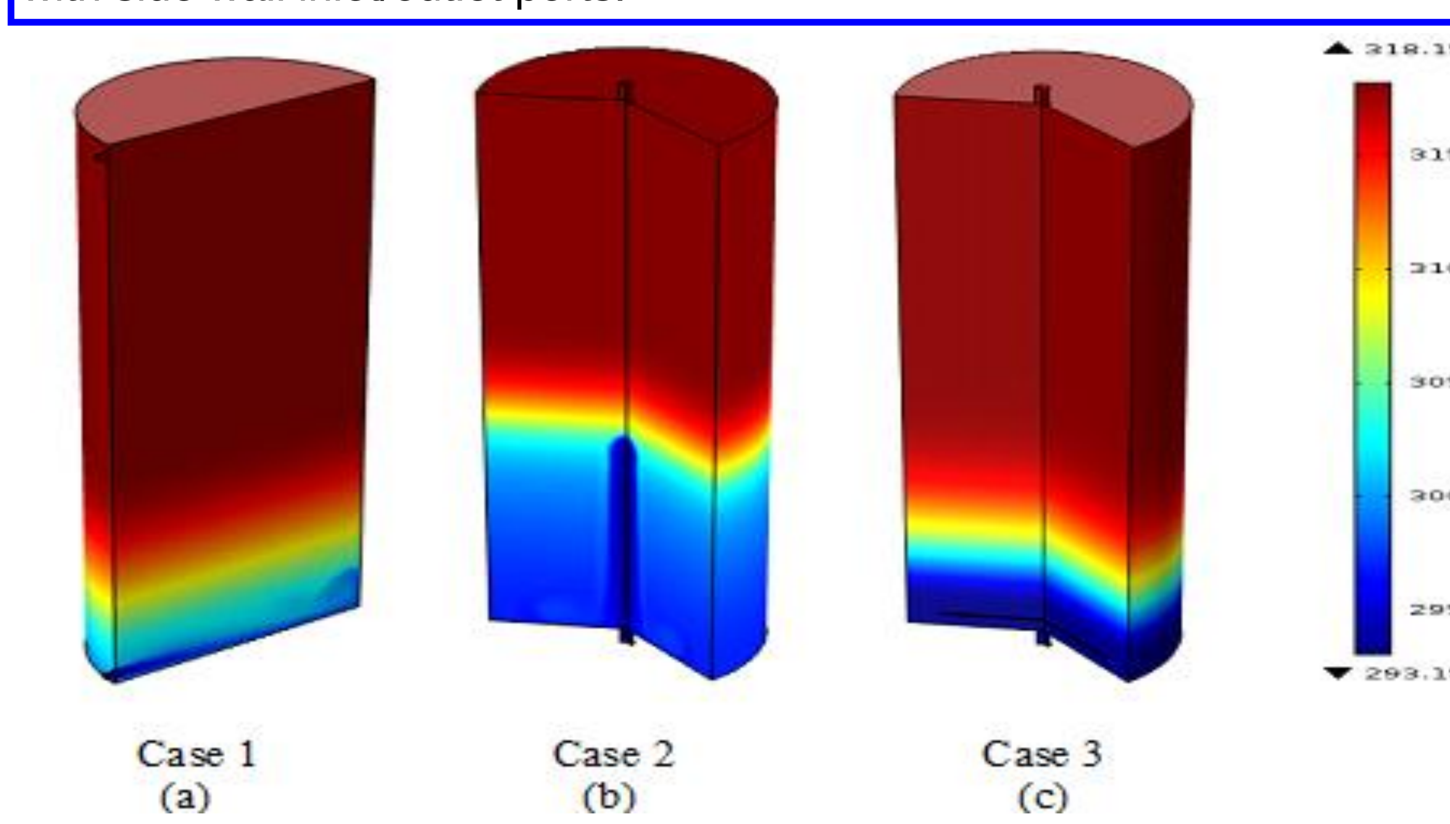

Figure 2. Comparison of centreline dimensionless temperature along the tank height at t = 1500 s; mass flow rate = 0.15 kg/s for the different cases

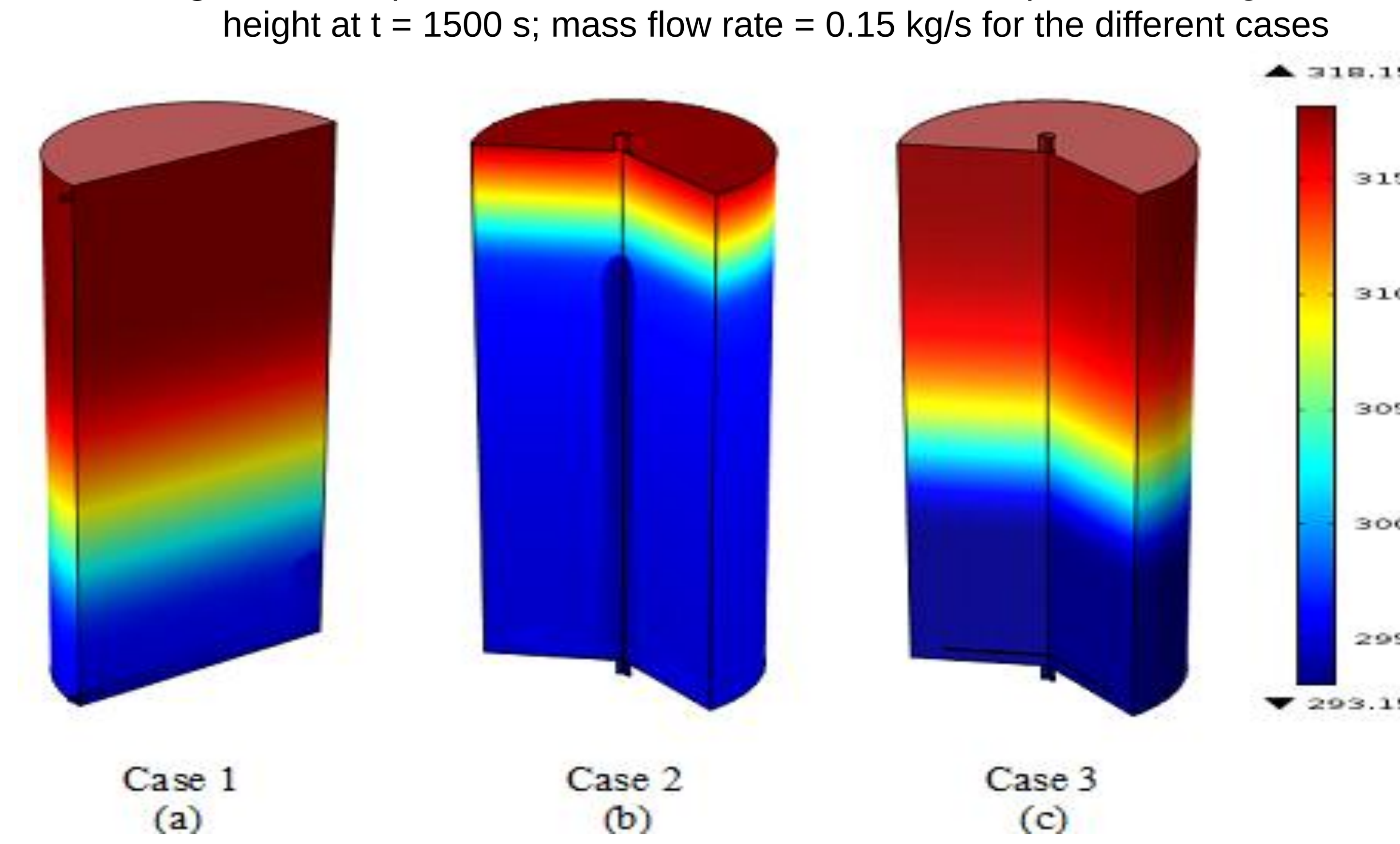

Figure 3. Comparison of centreline dimensionless temperature along the tank height at t = 3600 s; mass flow rate = 0.15 kg/s for the different cases

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 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 optimisation of solar thermally stratified energy storage tanks.

References

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Acknowledgement: *Funding for this work was provided by Natural Resources Canada through the Program of Energy Research and Development.*

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