Thermal Storage Tank Design Verification Using Computational Fluid Dynamics

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Thermal Energy Storage (TES) has a wide variety of applications, mostly related to heating and cooling purposes. For example, a chilled-water storage system shifts a part of the on-peak cooling load to a time when energy demand is low. Taking advantage of off-peak electricity tariffs, chiller units can be run at night when the cost is relatively low. In addition to the lower operating costs, the plant capacity can be reduced due to distributed load and chiller performance is enhanced due to cooler night air temperature, resulting in improved utility load factors.

In the present design of a TES facility, Computational Fluid Dynamics (CFD) simulation is widely used to ensure laminar heat transfer in the tank during charging and discharging cycles during the day. The charging cycle is operated at night when the tank is cooled down or charged with chilled water pumped into the TES tank and the discharging cycle will be during the day, when the stored thermal energy is being used or discharged to cool the building space.

The simulation result can be used to check the thermocline thickness of the any TES diffuser system, and re-designed if the design criteria are not met. This can be repeated till the design meets the criteria before fabricating a physical TES tank. This can save resources to reduce uncertainties in TES design.

The tank consists of two separate patent diffuser systems, one located at the bottom of the tank and one at the top. Each patent diffuser system is connected to several diffuser nozzles which supply water in to and out of the system.

During charging conditions, cold water at temperatures below 7°C will be injected from the bottom diffuser nozzles. The tank will fill up with cold water, which can take between 7 and 8 hours.

During discharging conditions, hot water from the hot spaces of around 14°C will be supplied from the top diffuser nozzles and the tank will be filled with hot water; this also takes 7-8 hours.

In this article, we will present examples of TES tank design and design verification results.

SIMULATION STRATEGY

The mixed water temperature layer thickness was determined using the real gas model even though the computation time was more than double that of the Boussinesq approximation model. To produce a more accurate simulation result, a real gas model was used to minimise and eliminate numerical errors that might occur in a simulation with the Boussinesq approximation model.

Figure 1 shows the comparison between the real gas and Boussinesq approximation model in temperature distribution. The temperature profile on the left shows the real gas model simulation at 4,380s which was about 1.2 hours. The mixed water temperature layer thickness, determined from the graphic visualisation, was 0.8-1.2m. The total number or operation hours simulation was

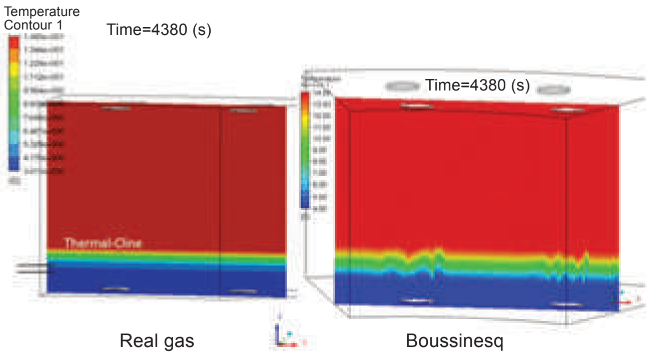


Figure 1: Temperature distribution comparison of Boussinesq approximation and the real gas model

simulated concurrently using the Boussinesq approximation model. The Boussinesq approximation model had faster convergence time in computing performance with some penalty in simulation accuracy.

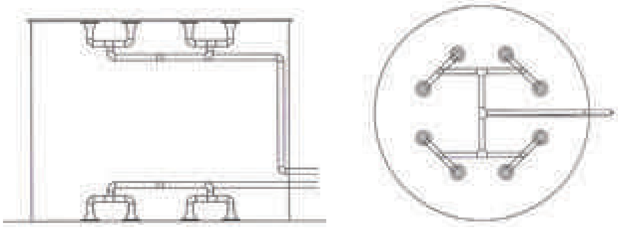
The transient calculation being employed for the CFD software was based on a fully implicit and conservative in time formulation. Each time step consisted of a number of smaller sub-steps, or coefficient loops.

A comparison of the timing required to conduce the analysis with the real gas model and Boussinesq model was done. A single coefficient loop calculation for the case using the Boussinesq approximation was measured to take 16 seconds of CPU time on average, while a single coefficient loop for the case using the real gas model took 23 seconds of CPU time on average.

In terms of the accuracy, it was found that the Boussinesq approximation running at a relatively larger time step, would have a negative effect on accuracy, particularly with numerical diffusion. However, the longer time requirements made this option unfeasible for use.

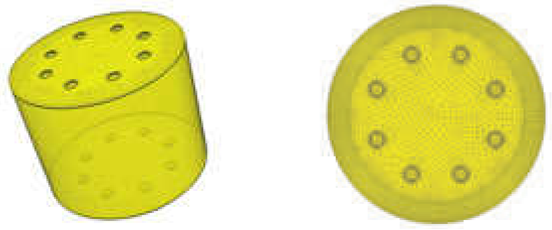
CASE STUDY 1

Case 1: Geometry



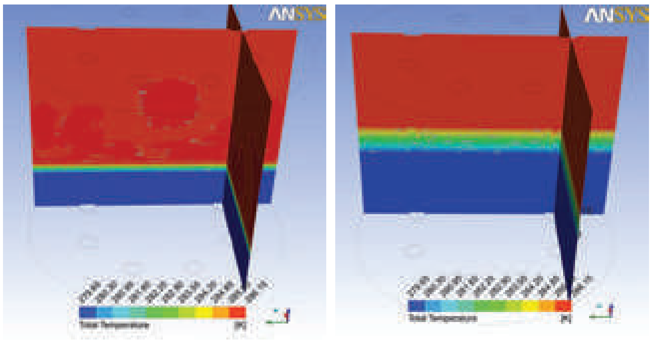
Front View *Top View*

Case 1: Computational Mesh



Isometric View *Top View*

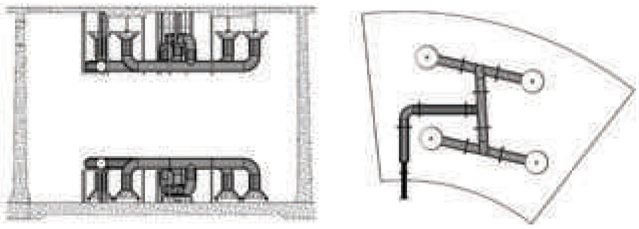
Case 1: Result of temperature distribution in (KELVIN)



Charging mode at 9300s (2hours 35 mins) *Discharging mode at 21600s (6hours)*

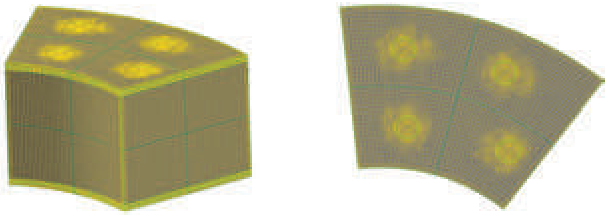
CASE STUDY 2

Case 2: Geometry



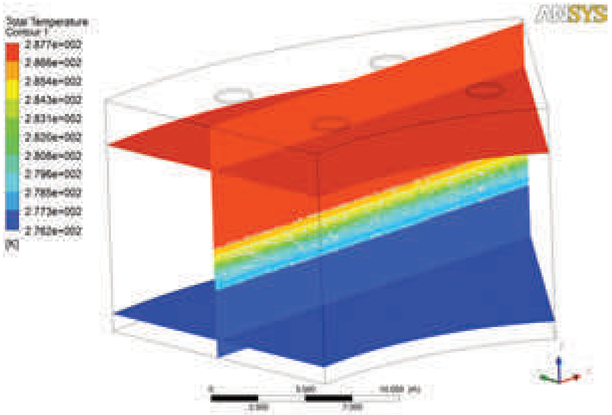
Front View *Top View*

Case 2: Computational Mesh

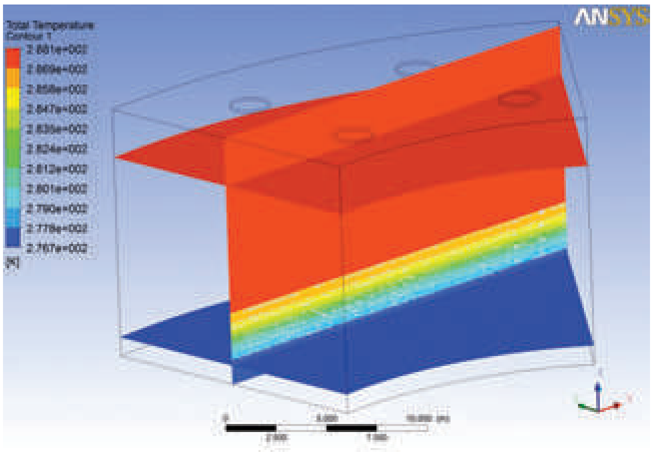


Isometric View *Top View*

Case 2: Result of temperature distribution in (KELVIN)



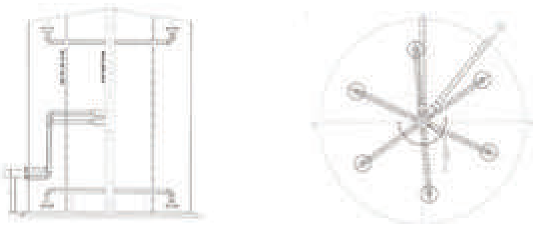
Charging mode at 12000s (3hours 20 mins)



Discharging mode at 25200s s (7hours)

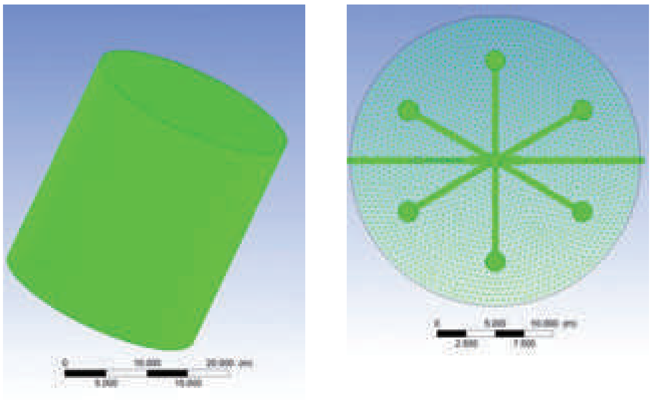
CASE STUDY 3

Case 3: Geometry



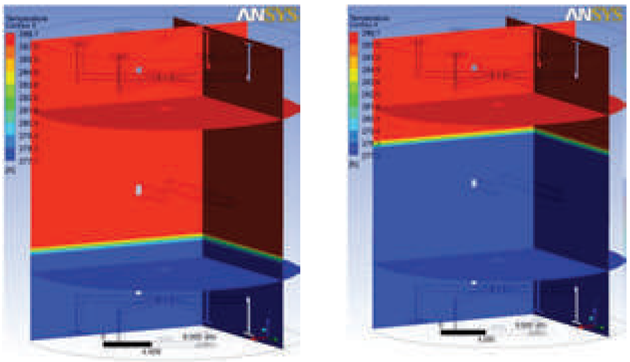
Side View Top View

Case 3: Computational Mesh



Isometric View Top View

Case 3: Result of temperature distribution in (KELVIN)



Charging mode at 8400s (2hours 20 mins)

Discharging mode at 10800s s (3hours)

CONCLUSION

The three case studies presented above show that the TES tank design can be of various shapes and configurations. The models have to be based on the actual size of the tank to reduce scaling error.

Computational mesh is developed in consideration of the complexity of the geometry. The transient simulation results can be extracted into a few representations of physical parameters, such as temperature and velocity distribution. Temperature distribution is usually used to verify the thermocline thickness of the design during charging and discharging for effective operation.

The CFD analysis shows that thermal stratification was achieved using both configurations at the given flow rate and temperatures for all three cases. The thermal efficiency is calculated using the thermal cline thickness information and using the equation below:

$$\text{thermal efficiency} = \frac{\text{Useable water volume}}{\text{Total water volume}}$$

CFD is used to simulate the flow behaviour for a thermal energy storage tank for both charging and discharging conditions. The CFD results are used to show a distinct thermocline and how the thermocline rises/falls with time. The thickness of the thermocline is determined, with thermal efficiency to be >95%.

In addition to predicting thermocline thickness, the numerical study will also prove that the hot water is displaced fully in the given time by the cold water for charging and vice versa for discharging. The direction of the thermocline movement and uniformity of the thermocline distribution horizontally are also determined for both charging and discharging transient operation condition. ■

Author's Biodata

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