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Improved thermal performance during standby period with baffles placed inside solar hot water storage tanks

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Thermal performance of solar hot water storage tanks is characterized by ambient heat loss especially during standby period. This is responsible for the formation of thermal stratification inside these tanks. In this regard, existing studies investigated the effect of a tank's orientation and aspect ratio (Fan and Furbo 2012), shape (Yang et al. 2016), wall thickness and material (Armstrong et al. 2014), and insulation shape (Kurşun 2018) on thermal stratification produced by heat loss. As mentioned above, research to date have focused on understanding thermal stratification created by heat loss but methods to curtail the rate of heat loss itself has been somewhat overlooked. Having said that, the potential reduction in the rate of heat loss through the use of baffles inside these tanks has not been well discussed. In particular, studies on the effectiveness of baffles on lessening heat loss when exposed to convective cooling boundary conditions are quite rare.

In this study, transient cooling of three cylindrical tanks equipped with baffles, having lengths that are 25%, 50% and 75% of tank height, and mounted at a distance that is 13% of tank radius from the inside cylindrical side wall, were modelled using computational fluid dynamics (CFD) along with the tank without baffle, as shown in Figure 1. Each 3 mm thick stainless steel tank has the storage capacity of 200 L, an internal diameter of 0.45 m with a height of 1.22 m, and was initially assumed to be filled with hot water at uniform temperature of 60 °C before being convectively cooled at a constant rate of $10\,W/m^2K$ to the ambient having the temperature of 20 °C. The computational methodology was validated with temperature, and velocity measurements using particle image velocimetry (PIV) data (Paing et al. 2019). A grid convergence index (GCI) with a safety factor of 3 was applied for the grid independence analysis, as suggested by Roache (1998). The calculated GCI between the coarsest (15 mm) and the finest mesh (7.5 mm) based on the average temperature of the tank showed a maximum error of 1.5%, indicating that a mesh with 15 mm cell size, was adequate. All baffles were initially assumed to be thin adiabatic sheets. However, thermally conductive and insulative baffles were also considered.

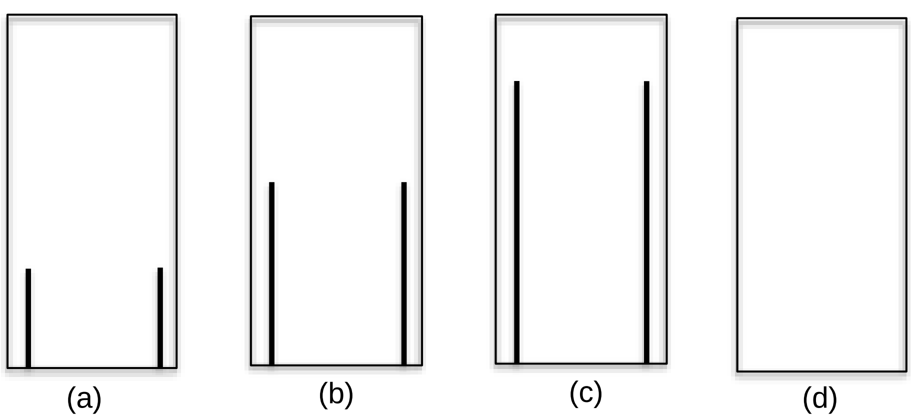

Figure 1. (a) Uninsulated tanks with baffle having lengths (a) 25%, (b) 50%, (c) 75% of tank height and (d) no baffle

It was found that the uninsulated tank equipped with an adiabatic baffle having the length of 75% of tank height incurs lowest rate of heat loss and able to maintain hot water at high temperature after 12 hours of standby period, as shown in Figure 2. This is because the baffle traps the cooled water inside thermal boundary layer between itself and the side wall of the tank which delays the formation of thermal stratification of water in the tank volume, as illustrated by temperature contours in Figure 3. However, this effect is attenuated with decreasing baffle lengths.

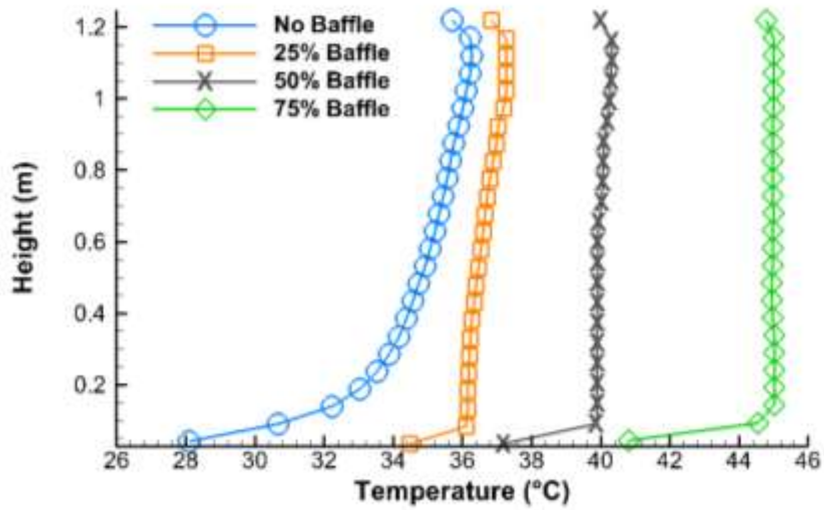

Figure 2. Axial temperature profile of water at the centreline of uninsulated tanks with adiabatic baffles having lengths 25%, 50% and 75% of tank height, and without baffle after 12 hours of standby period

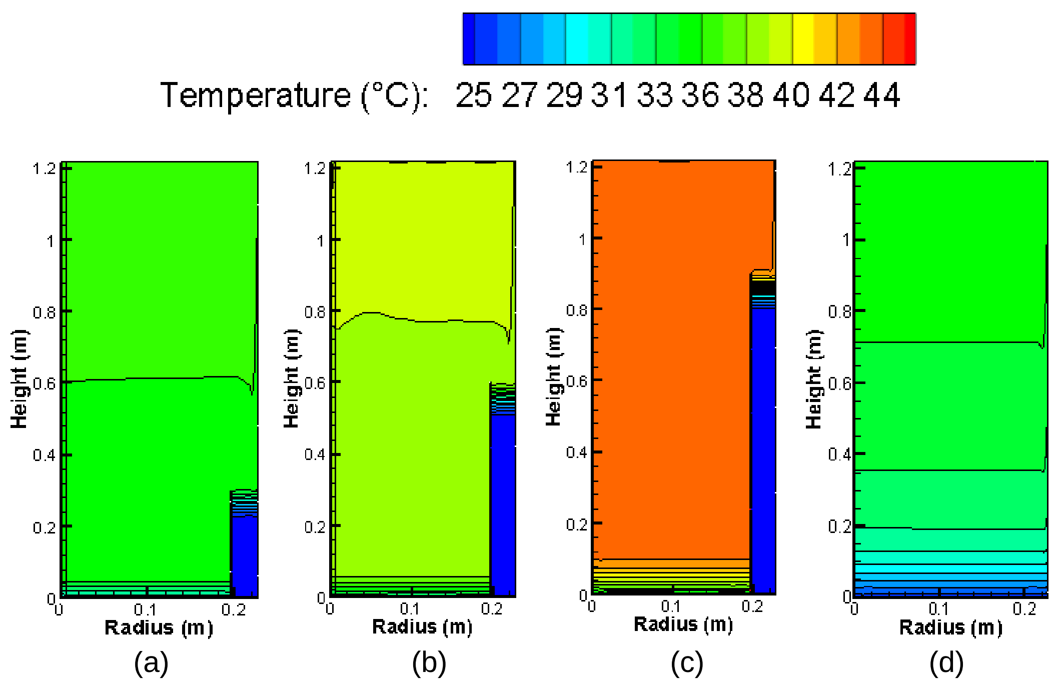

Figure 3. Temperature contours of uninsulated tank equipped with adiabatic baffles having lengths (a) 25%, (b) 50%, (c) 75% of tank height and (d) no baffle after 12 hours of standby period

Using the baffle that spans 75% of tank height, the influence of thermal conductivity of baffle on heat loss was examined. From Figure 4, it was observed that the tank equipped with adiabatic (fictitious) baffle is capable of maintaining the highest overall temperaure of water after 12 hours of standby period, followed by insulative (polypropylene) and conductive (copper) baffles. This is due to conduction heat loss from hot water to the baffle which is conducted from top to bottom within the baffle before it is lost to the water adjacent to the baffle. For the same reason, the maximum tempertaure difference of water inside the tank is lower in the case with conductive (copper) baffle compared to the one with insulative (polypropylene) baffle. Thus, it can be concluded that the effectiveness of the baffle declines with increasing thermal conductivity of the baffle.

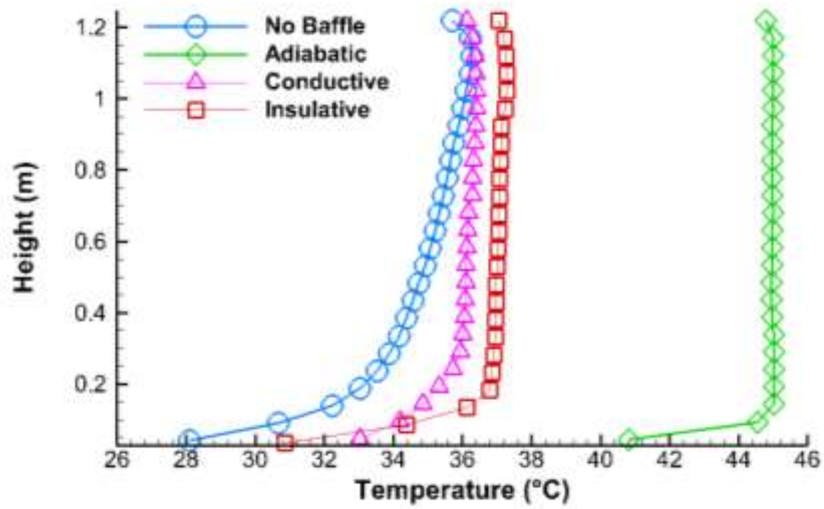

Figure 4. Axial temperature profile of water at the centre of uninsulated tanks equipped with adiabatic, conductive, and insulative baffles having lengths 75% of tank height after 12 hours of standby period

To analyse the effectiveness of baffle on typical solar hot water tanks, an additional insulated tank equipped with insulative baffle length of 75% of tank height was modelled along with an ordinary insulated tank. Both tanks are insulated enough to limit the rate of heat loss within the permitted rate of $30.9\ W/K\ day$ as per specifications of (AS/NZS:4234 2008) and (AS/NZS:4692.1 2005). From Figure 5, it can be seen that having an insulative baffle with 75% of tank height reduces the rate of heat loss, indicated by marginally higher overall temperature of water than the one without the baffle. Given that the tanks are well-insulated, and the heat loss occurs at a considerably slower rate than the case of uninsulated tanks, having a baffle only slightly improves the thermal performance compared to uninsulated tanks. The amount of energy saved from this improvement may not seem noteworthy on a daily basis, but it is expected that in the long run, the cumulative energy savings would add up to an appreciable amount.

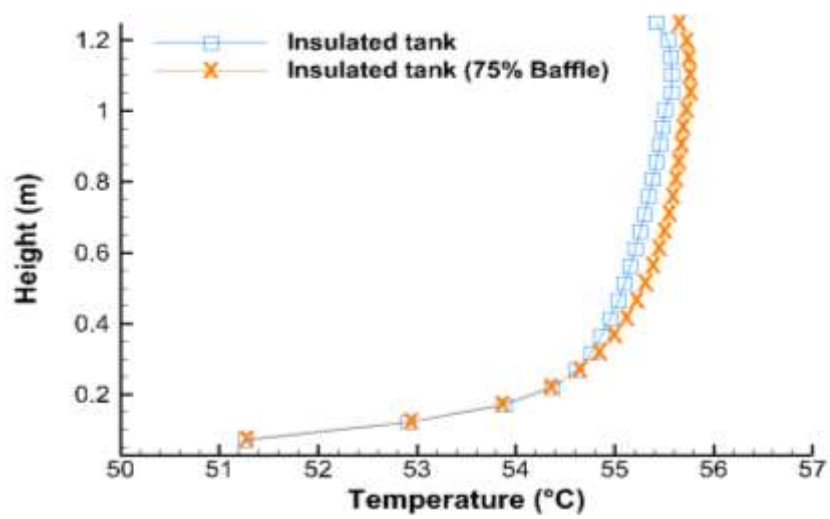

Figure 5. Axial temperature profile of water at the centre of insulated tanks equipped with insulative baffle having length 75% of tank height and without baffle after 12 hours of standby period

That being said, the proposed baffle configuration is found to be effective in improving the thermal performance of solar hot water storage tanks with minimal effort by reducing the rate of heat loss to the ambient during standby period.

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