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Study of the influence of inner lining material on thermal stratification in a hot water storage tank

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HIGHLIGHTS

- Thermal stratification in water storage tanks with different lining material is studied.
- A 3D CFD model has been verified and validated with experimental measurements.
- The process has been studied during charge (full and partial), and standby period.
- Three lining materials with very different thermal conductivities have been compared.
- Weak conducting lining material favors energy storage and stratification.

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ABSTRACT

The present study has analysed the influence of thermal conductivity of the inner lining material on the stratification process in a hot water tank during thermal charge and the later standby period. This analysis has been carried out numerically by a three-dimensional Computational Fluid Dynamics (CFD) model. Experimental measurements of temperature profiles are used to select and verificate the model, and to later validate CFD simulations. With the validated model, temperature over time at several heights, temperature profiles, velocity contours, water streamtraces and temperature contours, are studied and compared for three different inner lining materials. The obtained results confirm that a weak conducting lining material favours energy storage in the tank and the thermal stratification of water during charge and subsequent standby period. The effect of the inner lining material on the energy accumulated in water and on the moment of energy (stratification) is potentially enhanced when the material's thermal conductivity diminishes. The use of insulating paints as inner lining for water storage tanks could be a possible solution to be studied and subsequently adopted in practice to improve the efficient use of energy in stored water. The analysis techniques employed prove most useful and enable the results to be compared and presented in a novel way.

1. Introduction and objectives

Thermal stratification in hot water storage tanks, its improvement, preservation and degradation, have been the subject of numerous research works in recent years [1,2]. Many studies about flow in these energy storage devices have concluded that the effectiveness of thermal storage depends on many factors, including temperature ranges, flow rate, inlet/outlet diffuser, aspect ratio, thickness insulation, or tank wall thermal conductivity and thickness, among others [1–3].

In this sense, the influence of wall conduction on thermocline degradation processes has been investigated both experimentally and numerically and it has been concluded that heat loss through the conductive walls and insulation have a considerable effect on thermal stratification decay in storage tanks [4,5]. In order to diminish the axial heat conduction effect and to preserve or

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improve stratification, several studies have proposed insulating the inner wall surface by placing insulation material or any low thermal conductivity material compatible with stored fluid [6–9].

The aforementioned previous research works have been carried out with very basic one or two-dimensional numerical models, or with experiments that provide much less information and data than current ones can obtain. In numerical studies, one-dimensional models cannot describe the flow structure within the tank in detail, especially under high flow rate and complex structure conditions [1]. Moreover, even though current numerical studies are mainly two-dimensional, three-dimensional models provide more accurate and realistic results [10,11]. Accordingly, Computational Fluid Dynamics (CFD) modelling is a useful tool to analyse three-dimensional flows. Indeed, many references can be found in recent research works which used CFD to investigate thermal stratification within water storage tank [1]. The great majority of these studies have been focussed on the effect of tank design parameters such as the diffuser configuration [12] or aspect ratios and operating conditions [10,11,13–15]. Nevertheless, to our knowledge, no work analyses the effect of storage tank wall material on the degradation of thermal energy by using CFD.

This paper presents a numerical study of transient three-dimensional heat transfer and flow characteristics in a hot water storage tank by means of CFD for the purpose of improving thermal stratification and, consequently, overall system efficiency. The CFD model employed and validated in this paper focuses on the effects of inner tank wall lining material on the level, evolution and stability of thermal stratification over time.

In order to determine the influence of lining material, a comparative study of how temperature evolves at various heights is carried out. Three materials with very different thermal conductivities have been considered: steel, expanded polystyrene, and poly methyl methacrylate. Temperature profiles, thermoclines, velocity contours and water streamtraces, as well as the temperature contours in water and through tank walls are represented and analysed at different times. Likewise, the increment of energy and the moment of energy are calculated. The process is studied during the charge period (full thermal charge and partial charge), and also during the post-charge standby period.

2. Materials and methodology

2.1. Experimental setup and instrumentation

The tank prototype for hot water storage used in this study consisted in a prismatic vessel, constructed with 20 mm thick poly methyl methacrylate plates (PMMA). The inner dimensions of the vessel were 600 × 280 × 100 mm, with a water capacity of 16.8 L. The exterior was covered with a layer of insulating material: flexible elastomeric foam insulation, synthetic rubber-based (thermal conductivity, $k = 0.036$ W K^{-1} m^{-1}), 20 mm thick. The water inlet and outlets were located at the top and bottom of the tank. They were equipped with diffusers consisting of two parallel plates since it has shown that these devices improve the performance of thermal storage tanks by restraining mixing induced by water inflow [12,16–18]. Dimensions and constructive features of this prototype were conditioned because the tank was built with a dual purpose: on the one hand the mathematical modelling with CFD presented in this work, validated against experimental trials; and on the other hand, the determination and characterization of the flow velocity field applying the Particle Tracking Velocimetry (PTV) technique. PTV is a useful tool to complement numerical flow simulation results derived from approaches based on CFD. The results deduced from the analysis of the hydrodynamic performance of this hot water storage tank using PTV are not presented in this work.

Fig. 1 provides a schematic view of the tank. To record the water temperature inside the tank, two probes, each of 8 type T (class 1) thermocouples, were placed uniformly along the tank height. Two other thermocouples were used to record the water inlet and outlet temperatures in the tank during the charge period. After calibrating the thermocouples, the accuracy of the temperature measurements was considered to be ±0.1 K. Water flow was measured at the tank

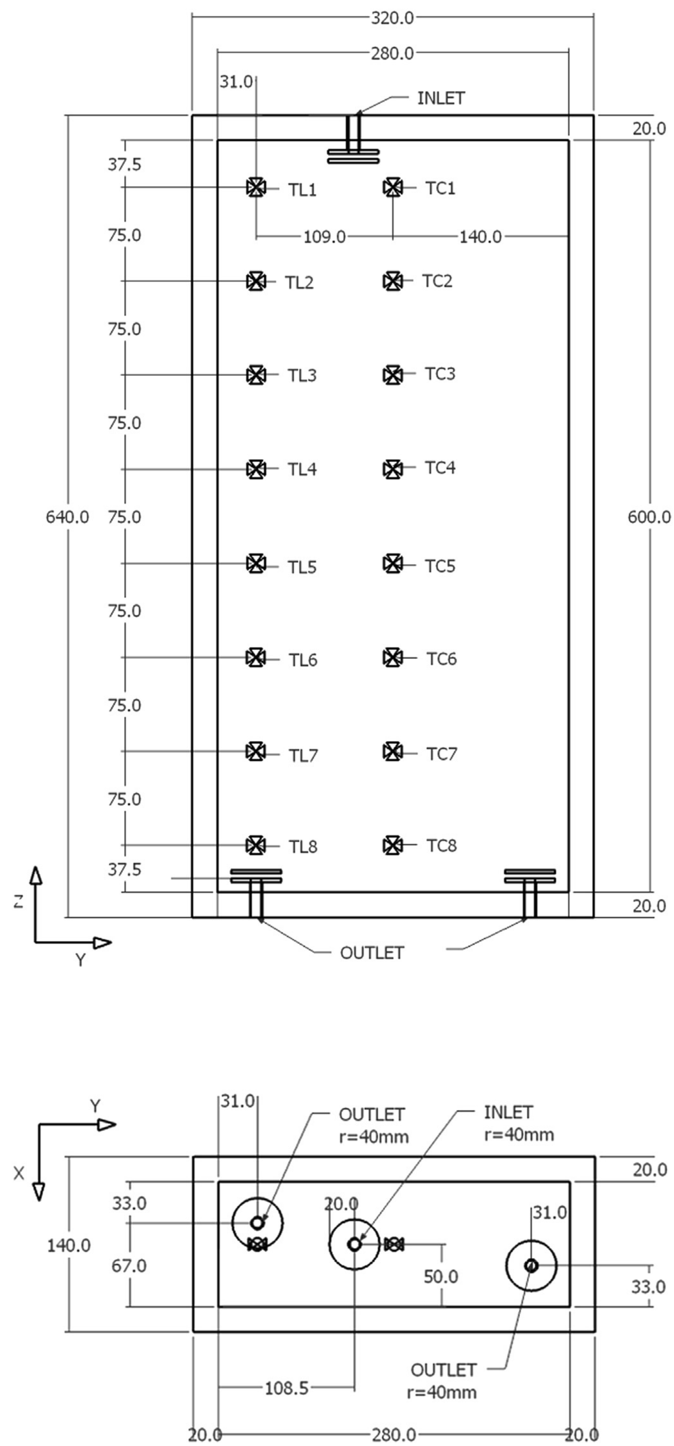

Fig. 1. Schematic view of the tank with its dimensions (mm). The position of the central (TC) and lateral (TL) probes with 8 thermocouples each is also indicated.