Prediction of thermocline zone development at the beginning of dynamic processes in single storage tanks with liquid media

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1. Introduction.

Thermocline development in tanks with liquid storage media is strongly affected by both turbulences and fluid mixing, which take place mainly at the inlet. The occurrence of these phenomena leads to an increase of thermocline zone thickness, which implies that less energy can be extracted from the storage tank. Different authors have attempted to include in their simulation models for single tanks with water the effect of turbulences and mixing in the development of thermocline zone [1], [2], [3], [4], [5]. In general they all propose correcting thermal diffusivity by introducing a coefficient that accounts for these phenomena. This coefficient usually depends on both Reynolds and Richardson numbers and is implemented either in the energy equation [1], [2] or in the boundary conditions [3], [4], [5]. All authors agree that it depends on tank dimensions; temperature interval and fluid flow, but also, on the tank inlet configuration since turbulences and mixing mainly occur at tank entrance. However, while some of them assume that this coefficient is constant [3], [5], others support that it has to be varied along the tank axial position decreasing its value as thermocline zone moves away from the inlet port [1], [2].

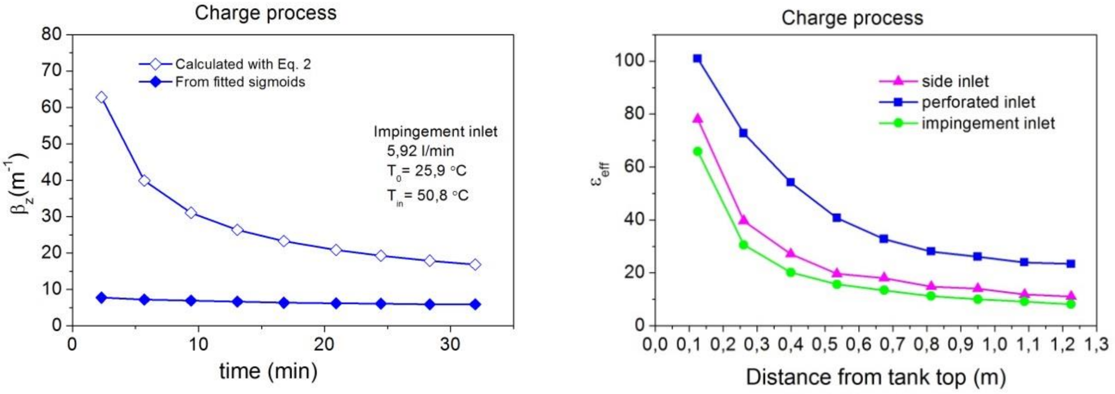
In spite of these attempts, the majority of simulation models for single tanks do not consider turbulence and mixing phenomena so that the prediction of thermocline zona development at the beginning of dynamic process is an issue that still remains unsolved. Therefore, the aim of this work is to improve the analytical model based on sigmoid functions developed in CIEMAT for thermocline tanks [6] in order to take into account mixing and turbulence phenomena. For that purpose the different approaches found in the literature will be implemented and the resulting improved analytical model will be validated with experimental data of water tanks. In a further step, it will be determined whether the new model is also valid for thermocline tanks with other kind of fluids like oil or molten salts, which are used in mid-high temperature storage applications

2. Implementation of the turbulence and mixing phenomena in CIEMAT analytical model

The experimental data of thermocline tanks with water from Zurigat et al. [1] have been fitted to the algebraic sigmoid proposed in our previous work [6] and the corresponding slope values at different tank axial position, β_z, have been obtained. In Fig. 1 a) these slope values for a charge process have been represented together with the slopes calculated with Eq. 1, which has been taken from the analytical model developed by Yoo and Park for simulating thermocline tanks also based on sigmoid functions [7]:

$$\beta_z = \frac{1}{2\sqrt{\pi\alpha t}} \quad [m^{-1}] \qquad \text{Eq. 1}$$

If we compare the slope values represented as a function of time, we observe that the experimental slopes are much smaller than the values calculated with Eq. 1. Since the slope of the sigmoid is related to thermocline thickness [8], this means that thermocline zone is larger than expected already from the beginning of the charge process. As stated in the introduction, this difference is due to the occurrence of the turbulences and fluid mixing at tank inlet and it is clear that the analytical model of Yoo and Park [7] does not consider these phenomena. Therefore, similarly to Zurigat et al. [1], we have introduced in Eq. 1 an *effective diffusivity factor*, ε_{eff}, that takes into account fluid mixing and turbulences during dynamic processes. This effective diffusivity has been calculated by fitting β_z with experimental slopes for tanks with different inlet configurations and has been represented as a function of tank axial position in Fig. 1 b). As expected, ε_{eff} value strongly depends on the kind of inlet and its value decreases to 1 as thermocline moves away from the fluid inlet, which was also observed by Zurigat et al. [1].



(a) (b)

Fig. 1: Comparison of sigmoid slope values from experimental data fitting with the calculated with Eq. 1 (a). Variation of ε_{eff} with axial position for different kinds of tank inlet (b).

In the paper, the functional variation of ε_{eff} with the distance from tank inlet and hence process time is established to that a mathematical expression can be implemented in the sigmoid equation of CIEMAT's analytical model. Moreover, the approaches proposed by other authors are evaluated in a similar way for determining which one is the most appropriate not only for being integrated in the sigmoid function but also for explaining and predicting the behavior of thermocline tanks at the beginning of dynamic processes.

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