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MEASURING OF TEMPERATURE PROFILES IN A THERMAL ENERGY STORAGE

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Abstract: This article deals with measuring of Temperature profiles of real thermal energy storage. Temperature gradients and thickness of intermediate regions (thermoclines) have been investigated within an industrially manufactured and marked storage. Several curves have been plotted to represent the temperature distribution at different times of the experiment and they have been compared with a hypothetical case of charging. The results show differences between the thermocline thicknesses of real case and the hypothetical case, but the temperature distribution trend curves are similar.

1. Introduction

Thermal stratification in water-thermal energy storages (TES) can considerably improve quality of obtained thermal energy, especially of low temperature heating systems. For various reasons, it is advisable to have an index or a measure to determinate the ability of TES to promote and maintain stratification during charging, discharging and storing cycles [1], [5]. In this context, there are often mentioned terms such as an efficiency of stratification or a rate of mixing (e.g. Davidson et al., 1994; Shah and Furbo, 2003; Panthalookaran et al. 2007; Huhn, 2007; Andersen et al. 2007). These indexes could be determined as being either based on the first law of thermodynamics (i.e. energy approach) or the second law of thermodynamics (i.e. exergy, or entropy approach) as proposed by Panthalookaran et al. (2007).

Different methods of how to characterize stratification efficiency in TES systems were used by manifold authors and they vary from author to author. Therefore, these methods could produce unequal results and however they include their advantages and disadvantages for evaluation of the stratification efficiency for particular storage processes, only some of the detailed analysis have been solved.

This article is built on the analysis of methods of how to determine stratification efficiency of TES (Haller et al., 2009) [1] and for the main target of this work it has been chosen experimental study of temperature profiles in real TES.

2. Hypothetical charging experiment

For detailed analysis and discussion of stratification efficiency is desirable to investigate storage with values derived from the experiment data (i.e. process of charging, storing and discharging). Experimental investigation of every case of every real TES could be difficult and often really time consuming. Therefore, a hypothetical experiment of charging, discharging and storing has been formulated.

The hypothetical experiment has the advantage of elimination of heat losses and the advantage of not being influenced by measurement uncertainties. The storage is filled with 1000 *kg* of water where the thermal conduction is assumed to be zero for reasons of simplicity. The whole content is divided into 20 horizontal layers of 50 *kg* each and the density is assumed to be constant for the case of hypothetical analysis. Other constants are the specific heat of water and the mass flow inlet of hot water in magnitude of 400 *kg/h* and temperature of 60 °*C* located at the top of the tank. The outlet vice versa is located at the bottom. Initial temperature of the TES is 20 °*C* for the case of charging. As proposed by Hollands and Lightstone (1989), the highest 25% mass of the storage is assumed to be fully mixed due to plume entrainment of the entering water-jet in every time step in magnitude of 0.125 *h* [Furbo1].

3. Non-dimensional values

For the reason of comparability of results between different experiments or at different times of experiments, non-dimensional values were introduced. They are usually derived for storage height *y** Eq. (1), temperature *T** Eq (2), and time *t** Eq. (3).

$$y^* = \frac{y}{H} \qquad [-] \quad (1)$$

$$T = \frac{T - T_{\min}}{T_{\max} - T_{\min}} \qquad [-] \quad (2)$$

$$t^* = \frac{t \cdot \dot{m}}{m_{store}} \qquad [-] \quad (3)$$

Where *H* represents whole height of the tank, T_{min} and T_{max} the lowest and the highest temperature encountered in the entire experiment. The non-dimensional time is based on the assumption of ideal plug flow of the inlet water $\dot{m}$ and minimum correspond to the start of the experiment. The maximum then correspond to the time when the whole volume of the storage (with the weight m_{store}) is replaced [Furbo1].

4. Experimental investigation

A quantification of the temperature gradient and thickness of the intermediate region (thermocline) could be one concept used to characterize the degree of stratification [2], [4]. For the experimental investigation of temperature profiles within the TES, it was used industrially manufactured and marked thermal energy storage NAD 1000, DZD Dražice, which can contain 1000 *kg* of water, Figure 1.

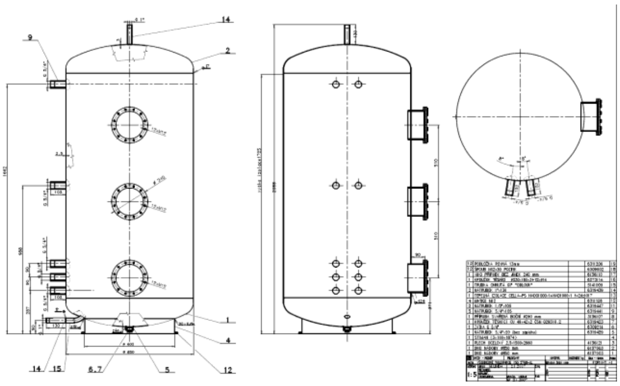

Figure 1.: Thermal energy storage used for experimental investigation.

The measuring of temperature profiles was made by more than sixty *K*-type thermocouples. The problem of wet thermocouples was solved by polypropylene tubes where the thermocouples were sealed and their outer parts were coated on their surfaces by a plastic, Figure 2.

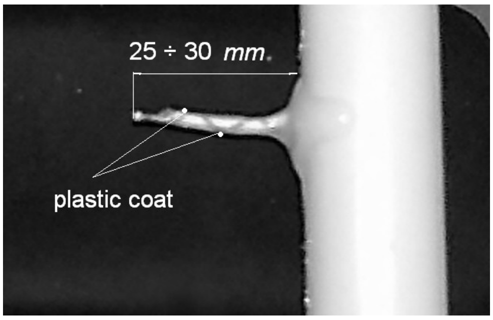

Figure 2.: The thermocouples inside of the TES.

The thermocouples were divided into three zones for the measuring of temperature profiles of 20 thermocouples in each zone. The placement of these individual zones is shown in the Figure 3.

The general configurations of the measurement setup were based on the hypothetical experiment which involves similar inlet temperature and mass flow of hot water. For the heating of the inlet water it was used another thermostatic storage. A view of experimental set-up is in the Figure 4.

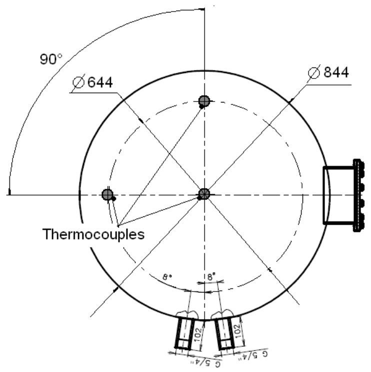

Figure 3.: The placement of the tubes with thermocouples inside.

The measured data were obtained by a Dewetron system designed to measure temperature and it allows an investigation of the time evolution of the temperature profile in the TES.

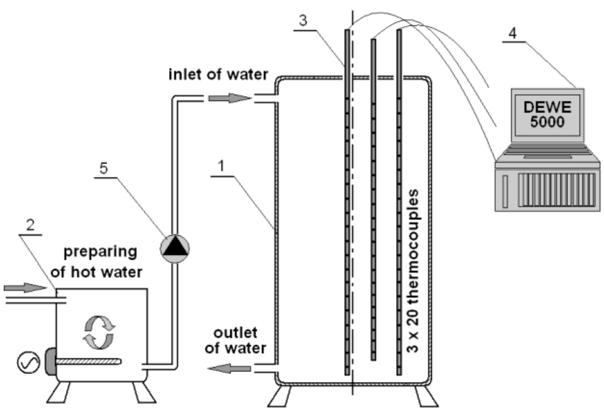

Figure 4.: The view of experimental set-up, where 1 is the storage NAD 1000, 2 is the thermostatic auxiliary storage with electrical heating, 3 are tubes with thermocouples within, 4 is the measuring instrument DEWE 5000 from Dewetron, 5 is the pump unit.

5. Results

The specified time step 0,125 *h* allows the replacing of water in any tank layer by the fluid from the adjacent layer above and its move to the adjacent layer bellow. Thereby, any numerical diffusion is eliminated in the calculation. In the hypothetical experiment, there were assumed 25 % of water inside of TES to be mixed in every time step, it means that in every time step five highest layers have the same temperature (Figure 5.).

The temperature differences between the incoming hot water and water inside the TES were decreasing during the experiment and although the mixing amount was still constant, the effect of stratification decreased. This effect corresponds with the rate of internal entropy production which has a downward trend during the hypothetical experiment. Although the rate of entropy generation is important for an investigation of stratification efficiency, it is not mentioned in this article.

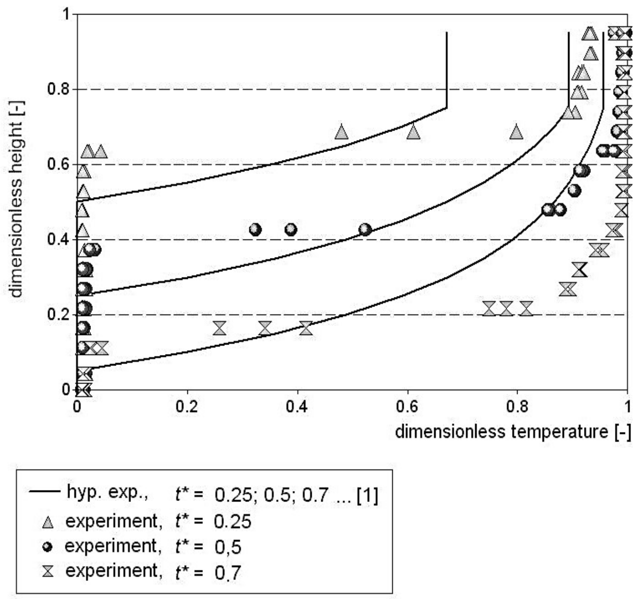

Figure 5.: Temperature profiles obtained from the hypothetical experiment and by the investigation of real TES.

6. Conclusion

In the Figure 5, there are compared the temperature profiles obtained from the hypothetical experiment with the data of real TES. Because of the similarity of both cases and using of non-dimensional values, the energy content should be similar in every time step. The thickness of the intermediate region of the hypothetical experiment is given by mixing of five highest layers and its thickness grows as time proceeds as well as in the case of the real TES, but the thickness of termocline obtained from the experimental data is thinner. This could be caused by a lower velocity of the inlet water.

In the case of investigation of the real TES, other parameters should be included as an influence of measurement uncertainties or heat losses to the ambient. It has to be therefore assumed that there will be obtained different results for two TES with same initial conditions but different boundary conditions, which could be influenced by different geometry. In any event, the trends of temperature distribution curves are similar for both cases.

Acknowledgment

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7. Literature

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