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# OPTIMAL DESIGN AND MANAGEMENT OF THERMAL STORAGE TANKS FOR MULTI-ENERGY DISTRICT BOILERS

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## ABSTRACT

As part of the second phase of the OptiEnR research project, the present work deals with improving multi-energy district boilers operation, by adding optimally sized and controlled thermal storage tanks to the plants. Previous studies focused on both a sizing approach based on a parametric analysis and an operation strategy. The aim of the present work is to improve the design of the tanks, in particular by evaluating the thermal losses and finding the adequate insulating materials. We focused on the stratification phenomenon and highlighted that the effectiveness of a thermal storage tank is related to the time during which the stored energy can be kept without considerable degradation. A case study allows the impact of thermal energy storage to be quantified.

## Keywords

Multi-energy district boiler, thermal energy storage, stratification phenomenon, thermal losses, optimal design, management strategy.

## 1. INTRODUCTION

Nowadays, the storage of energy in suitable forms is a scientific and technical challenge. A number of approaches have been investigated over the years to store thermal energy, including rock storage and phase change materials, but the most pragmatic solution is using water. Indeed, water is an excellent storage medium for low-to-medium temperature applications because of a high volumetric heat capacity, a low cost, very good security properties and widespread availability. Consequently, hot water tanks (for stratified thermal energy storage) are considered as an attracting technology and used in several industrial applications [1,2]. It should be noted that thermal stratification has a major influence on performance. Stratification can be impacted by turbulence inside the tank as well as thermal losses [3].

First, using discretization of time and space, a stratified tank has been modeled. The resolution of the resulting model allows the water temperature for each of the tank layers to be accurately estimated. Next, a design methodology based on a complete parametric analysis is proposed in order to optimize the tank shape and find the adequate insulating material. Then, we used the proposed methodology in order to design a 200 m<sup>3</sup> hot water storage tank that will be installed at a Cofely GDF-Suez multi-energy district boiler located in Northeast France (Alsace region). We carried out simulations in order to highlight the impact of the geometrical characteristics of the tank, its insulation and the weather conditions on the thermal losses. As a result, we found that heat losses have to be considered as a key factor when designing thermal storage tanks. Indeed, the efficiency of such systems is mainly related to its design and insulation.

## 2. MODELING OF THE TANK

In order to investigate the main factors leading to thermal losses, a model describing the thermal stratification phenomenon in the hot water tank has been developed. Unlike simplistic models in which temperature is supposed to be uniform throughout the volume of the tank, the proposed discrete space model, adapted from the “turbulent mixing model” [4], takes into account the existing temperature gradient. The tank is divided into  $N$  equal volume layers. When energy is stored, hot water is allowed to enter by the top of the tank and is assumed to mix with the  $m$  first top layers. In discharging (release) mode, the process described above is reversed. So, cold water is allowed to enter by the bottom of the tank and is assumed to mix with the  $m$  first bottom layers. Heat loss by conduction through the walls and by convection with the ambient air, conduction between layers as well as inlet and outlet thermal mixing are taken into account. The resolution allows the water temperature for each layer of the tank to be calculated.

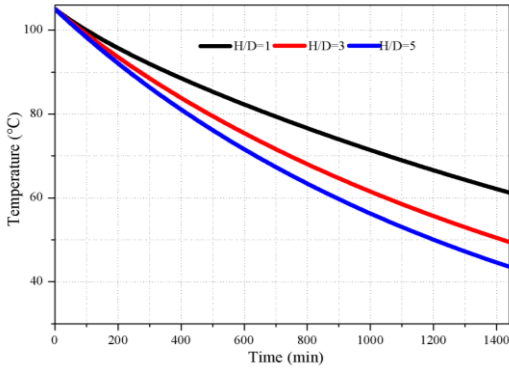
## 3. DESIGN OF THE TANK

As previously mentioned in the paper, the optimal volume of the thermal storage system can be defined on the basis of economic and energy criteria. However, a key point in the project is to design the tank by defining adequate geometrical characteristics as well as finding the insulating material allowing the thermal losses to be limited. To carry out this study, we used the model of the stratified water tank described in the previous section of the paper.

### 3.1 Case study

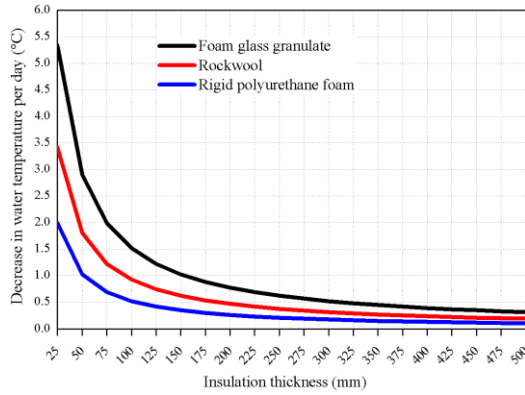
We selected as a case study a multi-energy district boiler managed by Cofely GDF-Suez. The plant, located in Northeast France (Alsace region), is connected to a heat network and equipped with a 4 200 kW biomass (wood) boiler and two gas boilers of 7 000 kW. A preliminary study, based on economic and energy criteria, has shown that 200 m<sup>3</sup> is the optimal size of the tank [5].

**Geometrical characteristics.** In order to define the adequate geometrical characteristics of the thermal storage tank, we evaluated in static mode (no water is passing through the tank) the impact of the ratio of Height to Diameter (H/D) on the thermal losses. We supposed that the 200 m<sup>3</sup> thermal storage tank is not insulated at all and initially filled with hot water at a temperature of 105 °C. The tank is not used during 24 hours. Outdoor temperature is supposed to be equal to 0 °C and unchanged through the day. Figure 1 highlights the way the ratio H/D impacts on the thermal losses. As it can be noted, by choosing for the tank a height equal to its diameter (H/D = 1), the average water temperature is decreased by 44 °C at the end of the day. Thus, such a temperature is 16 °C higher than when considering a ratio H/D equal to 5. So, we designed the tank as follows:  $V_{\text{tot}} = 200 \text{ m}^3$ ,  $H = D = 6.33 \text{ m}$ .



**Figure 1. Impact of the ratio of Height to Diameter (H/D) on the thermal losses (static mode, non-insulated tank).**

**Insulation.** The insulating material used and its thickness play an important role in the minimization of the thermal losses and, as a result, in saving energy. Figure 2 shows the impact of both the material used and its thickness on the thermal losses. If the objective is to lose no more than 1°C per day, the possible choices are: a 100 mm layer of Rockwool, a 50 mm layer of rigid polyurethane foam or a 150 mm layer of foam glass granulate. A definitive choice based on market price can then be made.

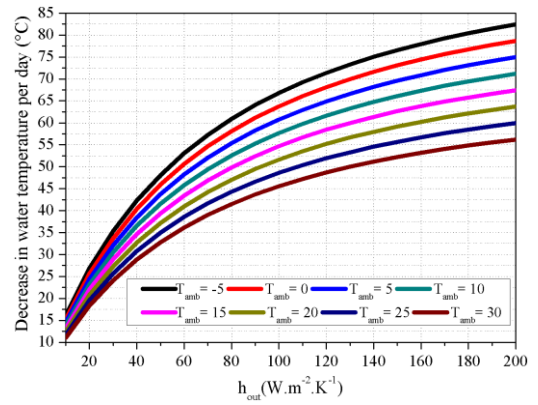


**Figure 2. Impact of the insulating material used.**

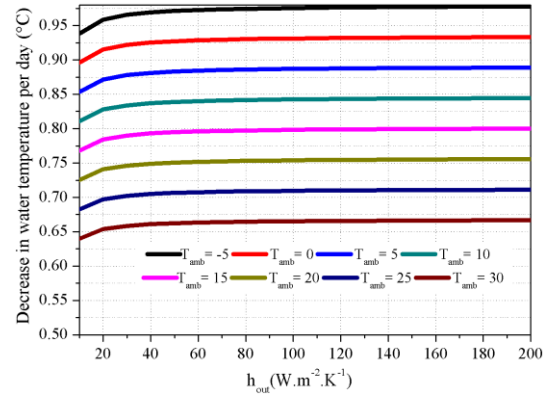
**Weather conditions.** Thermal losses are also influenced by the weather conditions, in particular outdoor temperature and wind speed. We carried out a parametric analysis in order to outline both the impact of the weather conditions on the tank operation during the cooling down phase and the way an appropriate insulation (e.g. a 100 mm thick layer of rock wool) can cope with unfavorable conditions. From Figures 3 and 4, we can easily notice that for a given ambient temperature, the impact of wind, implicitly considered through the heat transfer coefficient of air ( $h_{out}$ ), can be limited if the tank is well isolated. In addition, to limit the effect of forced convection created by the wind and prevent the tank to be subjected to very low ambient temperatures during cold days, it must be located in a place well sheltered from both the wind and cold (e.g. a place where it can be buried).

## 4. RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the designed thermal storage tank. Adding an appropriately shaped and correctly insulated storage tank to the plant can have economic and energy benefits. Insulation allows the thermal losses to be minimized, in particular when the tank is not used (static mode).



**Figure 3. Impact of the weather conditions in case of a non-insulated tank.**



**Figure 4. Impact of the weather conditions in case of an insulated tank.**

Volume	Height	Diameter	Insulating material	Thickness of insulating material
200 m <sup>3</sup>	6.33 m	6.33 m	Rockwool	100 mm

Table 1. Characteristics of the thermal storage tank.

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