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Thermocline Storage Tank with Concrete Filler.

Lessons Learnt During the Tank Erection Process in the Polyphem Project

Margarita M. Rodriguez-Garcia[1][https://orcid.org/0000-0002-0271-108X], Esther Rojas[1][https://orcid.org/0000-0001-5881-5331], Alain Ferriere[2][https://orcid.org/0009-0005-7606-5163], Lester Padilla[2][https://orcid.org/0009-0003-5038-6028], and Juan Caruncho[3][https://orcid.org/0000-0002-0270-9967]

[1] Ciemat- PSA, Spain

[2] CNRS-PROMES, France

[3] Arraela S.L., Spain

Abstract. A thermal storage of 2500 kWh is designed, built and installed at the site of the experimental solar tower of Themis in Targasonne (France) within the POLYPHEM project (H2020 program, Ref N. 764048). The thermal energy storage (TES) consists of a thermocline tank with solid filler and thermal oil as heat transfer fluid. Tank walls, filler bricks and foundations are made of concrete. This new concept introduces some challenges that have been addresed during the construction and commissioning of the TES system. In this paper, authors present the main issues and solutions adopted for the tank design and construction.

Keywords: Thermocline Storage, Concrete

1. Introduction

A 2 MWh net capacity thermocline thermal storage has been designed and built at THEMIS within the POLYPHEM project (H2020 program, Ref N. 764048). The main specific features of this thermocline tank are to have a structured filler and to use concrete everywhere: tank walls, filler and foundations. Two concrete formulations, patented by Arraela, were chosen as construction materials: HEATEK-RV® for tank walls and filler while HEATEK-RC® is used for the insulating top foundation slab. Since HEATEK-RV® was going to be in contact with the oil HTF of the Polyphem bottom cycle, as presented by Ferriere et al. [1], several compatibility tests were performed, showing negligible diffusivity of the oil into the different concrete samples, as presented by Ferriere et al. [2]. As detailed in Rojas et al. [3], the test procedure to test the concrete compatibility with oil was the following:

- Samples of oil and solid materials were characterized prior to testing.
- the relative atmosphere in the autoclave is kept under N2 @ 2 bar and automatically regulated.
- Daily heating/cooling cycles are performed in the temperature interval: 100-330ºC, with a heating time of 5h, cooling time of 15 h and stand-by time of 2 hours at each minimum and maximum temperature.
- The test-cell is heated up using electrical resistors and it is cooled down from the bottom using water flow.
- Test duration is about 1000 hours (42 days).
- Solid materials and oil are characterized after testing.

No penetration of oil in any of the concrete samples was observed. Additionally, the structural properties of the concrete samples after the testing showed no mayor changes. In any case, and just as a conservative approach, since piping had to go through the concrete walls, this piping was provided with double annular fins in order to prevent any unexpected oil leakage [4].

According to thermal initial simulations [3], based both CFD analysis and simplified modelling, a cylindrical tank of 2.6m inner diameter and 3m high was defined in order to have a 2.6 MWh gross storage capacity. The structural analysis performed by an engineering company defines a 0.5m tank wall thickness, 0.4 m thickness for the insulating foundation slab and the required reinforcement. Several types and configurations of the structured concrete filler have been studied by Rodriguez-Garcia et al. [5]. Nevertheless, none of these configurations assured a good enough heat transfer between the oil and the concrete so the design was for a commercial hollow bricks shape. The size of these bricks was increased because, when manufacturing the bricks, it was observed that, due to the relatively high forge velocity of HEATEK-RV and the 1cm wall thickness of the commercial size bricks, the mass segregates, breaking the bricks at the exit of the production machine [6]

In the following paragraphs, the modifications that were required to apply when this former design was translated to a real system are explained. Nearly there was no previous experience on erecting an aerial concrete tank for thermal energy storage. The lessons learnt are explained as well as some proposals for optimizing the design and its erection are suggested.

2. Redesigning and construction of the tank

The final overall design of the TES Polyphem tank was that shown in Figure 1 and Figure 2. The main differences in relation to the initial design are the following:

- Dodecagonal section instead of a circular one. Cylindrical formworks of the required dimensions were much more expensive and difficult to find that those with a dodecagonal shape.
- The tank height has been enlarged up to 3,2m. In this way, the self-tank acts as the oil expansion tank. A level measuring gauge was included for control issues. The top free surface of the oil is at ambient pressure.
- A metallic lid is used instead of a concrete lid. This decision was based more on facilitating managing of the lid to allocate it on the top of the tank.
- Piping going through the concrete does not have any fins. The outer and inner tank formworks will be kept after concrete curing (what is known as lost formworks). These formworks will then act as measure for preventing any oil leakage.
- An additional insulating layer between the HEATEK-RC® and the tank base is included. It is a sandwich made of a metallic sheet and a silicate layer. The first one is to homogenize structural loads so that the silicates layer does not suffer because of the hollow shape of the insulating layer (Figure 3).

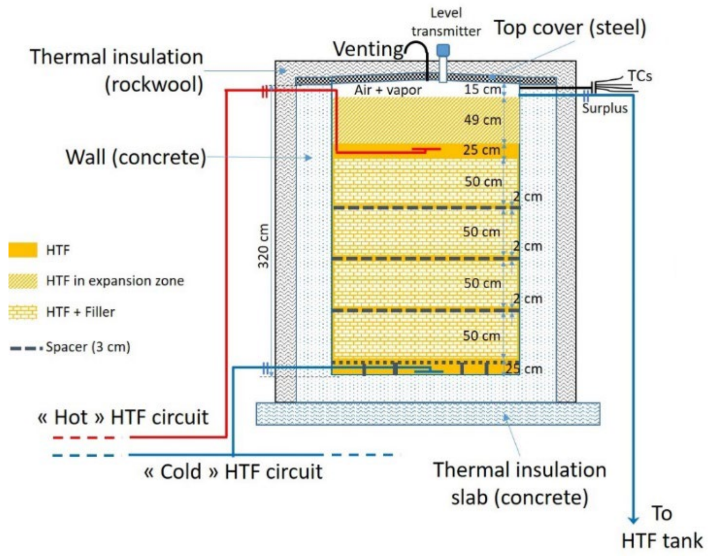

Figure 1. Polyphem TES tank scheme as it has finally been constructed. Frontal view.

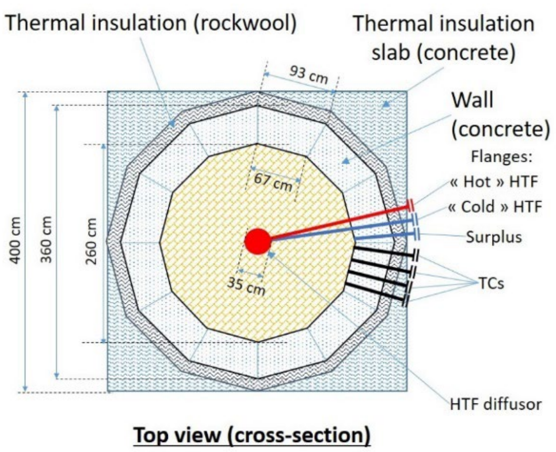

Figure 2. Polyphem TES tank scheme as it has finally been constructed. Top view.

(a) (b)

Figure 3. (a) Insulated slab made of HEATEK-RC® large pieces and (b) the whole insulation for the foundations, including silicates layer.

Once the insulating layers were placed on site, an external lost formwork was installed and the reinforcement erected. Although most of the rods of the reinforcement were previously bent, the welds between them were done on site. The reinforcement proposed is very heavy (see Figure 4), so when welding rods their vertical alignment changes a bit. Since there was no previous experience with this type of construction (aerial concrete thermal storage tanks), a conservative approach (according to the ANSI code) was followed and alignment of the rods was checked and corrected each time, with the corresponding time consumption.

Figure 4. Reinforcement view while erected and detail from inside.

When pouring the HEATEK-RV® concrete in the formworks, its aluminate cement nature was revealed to be very critical. Aluminate concretes have to be handle with appropriate measures that are not the usual ones for another types of concretes, like OPC concretes, as stated by Sanchez Pirez in [7], mainly because its forge velocity is very large. Several unsuccessful attempts of concrete pouring were suffered, so delaying aggregates were necessary to be used. A great mount of concrete was dismissed because it becomes cured and hot before it was poured into the formwork (Figure 5).

The tank walls were externally insulated with Rockwool® and aluminum sheet envelope.

2.1. Optimizing tank erection

From the experience gained during the erection of the concrete storage tank some issues arose. A pumped concrete mixer is required in order to pour it as quick as possible. The reinforcement may be optimized, lighting it and being erected with such a great accuracy as it was this time. Additionally, the lost formwork should become a removable formwork, overall, the one in the inner surface of the tank walls to avoid the current expected thermal bridges between the top and hottest part of the tank and the bottom and coldest part of the tank. Coming back to a design with annular fins for that piping going through the concrete would prevent oil leakage, if any.

Figure 5. Manual pouring of concrete within the frame work and view from above of the tank with the concrete walls –blue rods kept the inner formwork at its position; they are removed after the concrete becomes complete cured and dry.

3. Redesigning and allocation of the filler

The initial overall dimensions of the concrete bricks had to be reviewed since when manufacturing the bricks it was observed that, due to the relatively high forge velocity of HEATEK-RV® and the 1cm wall thickness of the bricks, the mass segregates, breaking the bricks at the exit of the production machine. Bigger bricks were manufactured maintaining the sizes of the hollows but increasing the number of those, [6].

When the tank was constructed, the bricks were allocated within the tank. The rectangular shape of the bricks cannot match the dodecagonal shape of the tank. In addition, the dimensions of the bricks are not congruent with the size of the tank. The objective was to minimize the voids between the filler bed and the wall of the tank, and to minimize also the number and the complexity of cutting of bricks. A pattern was created which meets these two requirements. It is represented in Figure 6 (left). In this pattern, each row of bricks is composed by 131 full bricks plus 10 bricks with cut.

In total, 20 rows of bricks are superposed, forming 4 stacks of 5 rows. The stacks are separated by metallic grids, which enable the horizontal circulation of thermal oil and facilitate the installation of thermocouples inside the filler bed. The grid is shown in Figure 6 (right) and in Figure 7 (left). Moreover, each stack is rotated by 30° with respect to the stack beneath, as it is shown in Figure 7 (right). Therefore, the voids left by the bricks in some sides of the pattern are covered by the next stack of bricks. Finally, the upper diffusor of thermal oil in the tank is welded to a tube passing through the wall, this latter tube being itself welded to both the inner and the outer metallic lids, as it is shown in Figure 8 (right). Any risk of leakage is avoided. Furthermore, the hot oil pipe is horizontal which prevents to trap air during the filling of the tank.

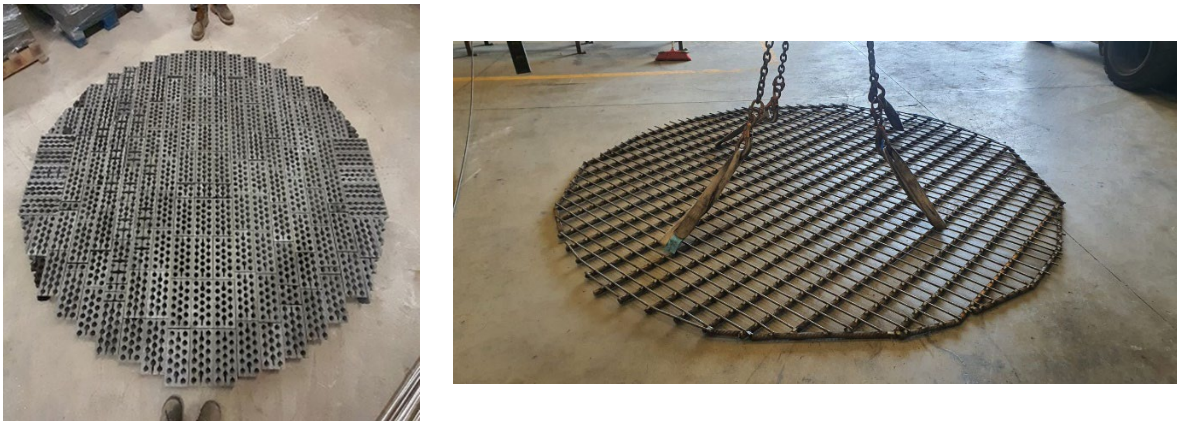

Figure 6. Allocation of the filler bricks in the tank. Left: pattern; Right: metallic separator.

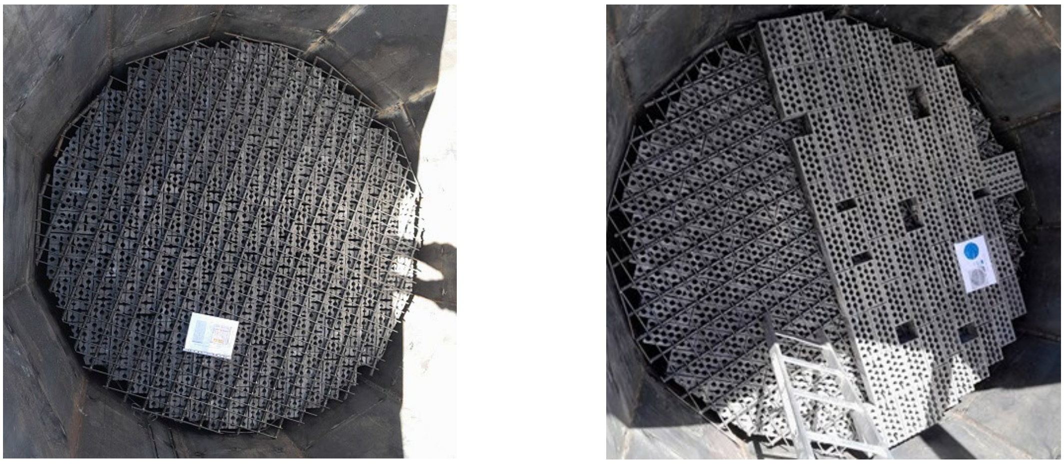

Figure 7. Metallic grid between two stacks. The superposed stacks are rotated by 30°

Figure 8. Thermal expansion volume above the filler bed (left); Upper oil diffusor (right).

Author contributions

Margarita M. Rodriguez-Garcia: Conceptualization, Writing-review & editing; Esther Rojas: Conceptualization, Writing-original draft, Visualization; Alain Ferriere: Resources, Writing-review & editing and Juan Caruncho: Investigation, Resources, Project Administration

Competing interests

The authors declare no competing interests.

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