Development of Overground Hot Water Stores in Segmental Construction for Solar and District Heating Systems within the Project OBSERW

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Abstract

Thermal energy stores can significantly improve the efficiency and environment-friendliness of the heat supply. Therefore, a high demand for cost-effective storage systems with low energy losses exists. This contribution deals with thermal energy stores for heat supply systems and presents a new aboveground store in segmental construction that allows temperatures up to 98 °C. The construction of a demonstrator is part of the OBSERW project, where researchers show the advantages of this technology, particularly regarding thermal insulation and storage efficiency.

Keywords: district heating, floating ceiling, heat supply, hot water, segmental construction, solar heating, thermal energy storage, thermal stratification

1. Introduction

Thermal energy stores can make heat surpluses available to the consumer if necessary. A thermal stratification inside the storage tank is achieved by separating water with different temperatures through buoyancy. In a storage tank operating according to the displacement principle, a water exchange takes place by direct charging and discharging.

Significant potential for optimization can be identified by comparing currently available storage technologies, in particular pressure vessels and flat-bottom tanks as illustrated in fig. 1 and 2. Pressure vessels (b) allow higher storage densities as well as higher temperature differences but often have low storage volumes, higher heat losses and higher investment costs. However, flat-bottom tanks (a) combine large volumes with relatively low costs. A drawback is that a second zone, respectively a higher fill level is required to apply a hydrostatic load. Furthermore, for safe operation low-pressure steam or an inert gas in the attic is mandatory. This leads to higher heat losses, unfavorable thermal stratification and operation conditions plus unused storage volume. A new storage tank design eliminates these disadvantages and offers numerous benefits. A demonstrator was already built in cooperation with industrial partners as part of the OBSERW project (see also Urbaneck et al., 2017), which will be presented here.

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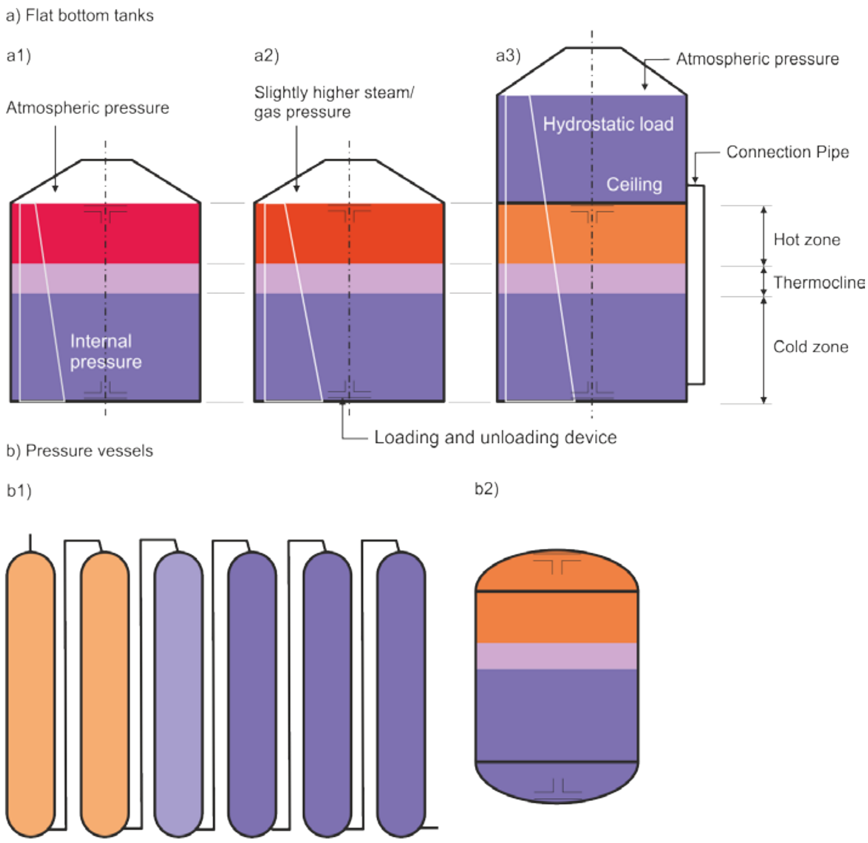

Fig. 1: Overview of storage tank constructions, Urbaneck et al. (2016b)

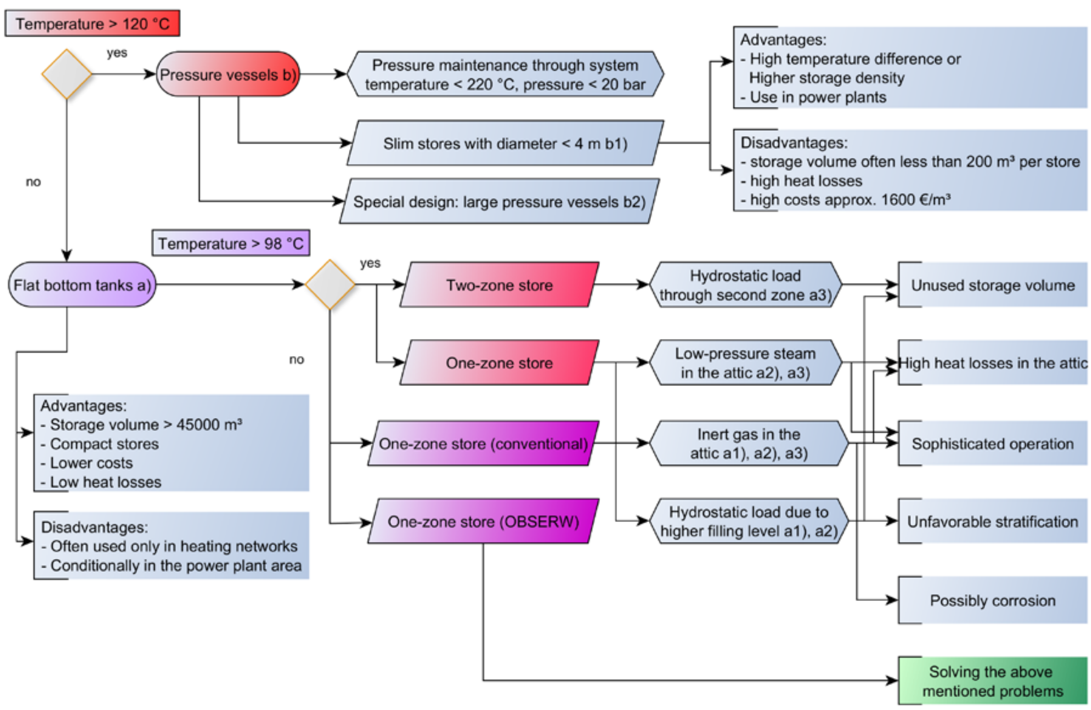

Fig. 2: Systematization and characterization of large hot water storage tanks, Urbaneck et al. (2016b)

2. New Storage Tank Design with a Floating Ceiling

In contrast to welded flat-bottom tanks, respectively pressure vessels a storage tank design with bolted and sealed segments has already proven to be advantageous for large cold water storages (Urbaneck, 2012) for the following reasons:

- use of storage tanks at ambient pressure for cost reasons compared to pressure vessels (use of thin-walled metal sheets, minimization of material),
- thereby avoiding classification in pressure vessels (avoidance of cyclical checks, etc.), storage tanks are considered as a building with simple permission,
- elimination of excavation in comparison to underground reservoirs (strong cost reduction),
- significant reduction of problems with regard to the accumulation of moisture in the thermal insulation (reduction of the thermal resistance of the thermal insulation, impairment of the long-term durability),
- easy geometric design with sufficient storage tank height (essential prerequisite for operation with thermal stratification),
- more efficient construction technology and logistics and therefore faster production,
- unproblematic use in many places (e.g. no geological requirements).

In principle, this storage tank design is also of interest for hot water storage tanks. However, this technology cannot be transferred to high operating temperatures (up to 98 °C) or use in local and district heating systems without further research and development work. Thus, several adaptions of the design are necessary.

The main novelty of the new construction is an indoor protected floating ceiling with the upper loading device (e. g. a radial diffuser) attached directly to it, as shown in fig. 3. A flexible connection allows the free movement of the floating ceiling between a top and bottom dead center. During charging of the tank a gravity current occurs directly at the ceiling, which is an essential prerequisite for a good thermal stratification (Findeisen et al., 2017a). When discharging, hot water is sucked straight along the ceiling, which allows the full use of the warm zone. The aim is to operate the storage tank with a maximum temperature of 98 °C. The elimination of a hydrostatic pressure relief means that there is a risk of falling below the steam pressure limit. This has to be avoided, as it could lead to cavitation or other transient effects during discharging. A free-form radial diffuser lowers the local pressure drop due to its flow-optimized shape and thus improves operation safety as recently shown by Findeisen et al. (2017b, c). A flexible sealing and the pressure compensation pipe ensure volume and pressure compensation in both storage tank and attic. This allows the storage in combination with a pressure-increase or pressure-reduction installation, to provide functions such as pressure maintenance as integration into heat supply networks (Urbaneck and Platzer, 2015). The pressure compensation pipe is also used for independent ventilation (e.g. during commissioning) and secures the storage tank against overpressure and underpressure. This may also occur, e.g., when the appliance is not in use and the water level falls while the floating ceiling rests on the support (bottom dead center). The floating ceiling and the flexible sealing avoid a gas input into the storage water and thus help to avoid corrosion in the system. Furthermore, flexible sealing lips are located at the edge of the ceiling to suppress free convection between the ceiling and the storage tank wall. As a result, heat losses are reduced and the flexible sealing is less thermally stressed. For the construction of the ceiling, bolted and sealed segments are provided which can be easily filled with a blow-in thermal insulation material. The use of plates is also conceivable. Compared to other constructions, the thermal insulation is located directly on the hot zone, which is topologically the best solution. The storage roof protects the thermal insulation from weather influences. Since the attic can be equipped with ventilation, drying is possible if humidification occurs (e.g. temperature falls below dew point in winter).

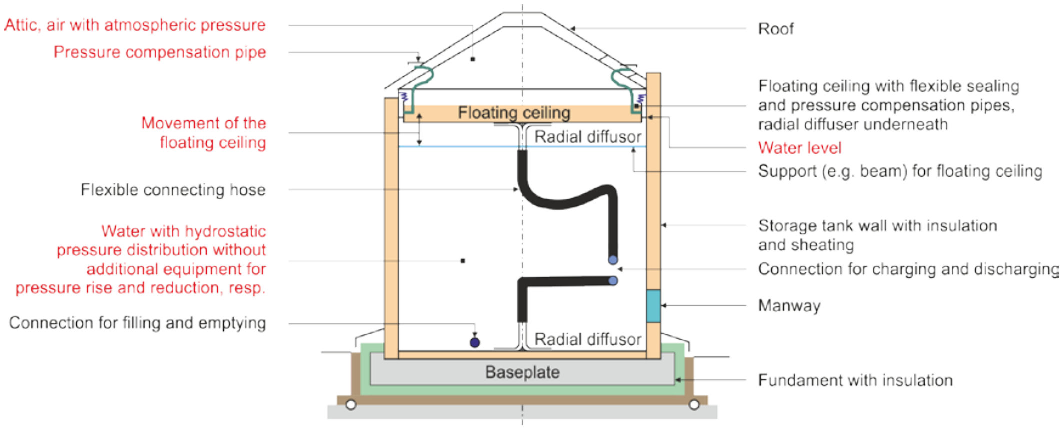

Fig. 3: Aboveground thermal energy store with floating ceiling and directly mounted radial diffuser, Urbaneck et al. (2016a)

3. Concept and Project Organization

The aim of the project is the development of a storage tank in segmental construction as proposed in fig. 3 with a volume from 500 to 8000 m³ that should be suitable for the following applications:

- district heating networks with central heating power plants and combined heat and power generation, used in the grid area (typically for short-term storage),
- local heating networks with decentralized combined heat and power plants (typically for short-term storage),
- large solar heating systems (short- and longterm storage),
- systems with industrial waste heat.

For a tank design which meets these goals several sub-problems must be solved. First, temperature- and water vapour diffusion-resistant roof and wall structures must be designed, with a special focus on the seal between the floating ceiling and the tank wall. In addition, improvements to the thermal insulation design must be undertaken, including the use of innovative substances and the elimination of thermal bridges. Advances in charging and discharging design are required. Finally, methods for better integration into existing networks, and reduced cost, on-site manufacturing procedures should be developed.

The consortium carrying out this project consists of the following partners:

- Chemnitz University of Technology, Professorship Technical Thermodynamics (TUC/TT): accompanying research and coordination of the collaborative project;
- University of Stuttgart, Institute of Thermodynamics and Thermal Engineering, Research and Testing Centre for Thermal Solar Systems (ITW/TZS): accompanying research;
- Farmatic Tank Systems (FTS), Nortorf (Germany): practical oriented development and demonstration.

Fig. 4 shows the procedure to solve the named subproblems. After defining requirements and three typical storage tank sizes, in a first stage fundamental investigations of the materials were carried out by Lang et al. (2016) and Gerschitzka et al. (2016). Furthermore, Urbaneck et al. (2016b) and Findeisen et al. (2017) verified the benefits regarding storage tank design and loading behavior. In a second and ongoing stage, practical tests on a special test rig in the laboratory (fig. 5) help to understand the characteristics of multilayered wall structures in detail. In the third stage, theoretical and practical results are transferred to the demonstrator. Here, many different tests are in progress to secure the technical feasibility and to prove the substantial benefits compared to other storage tank technologies. For this purpose, accompanying measures are provided.

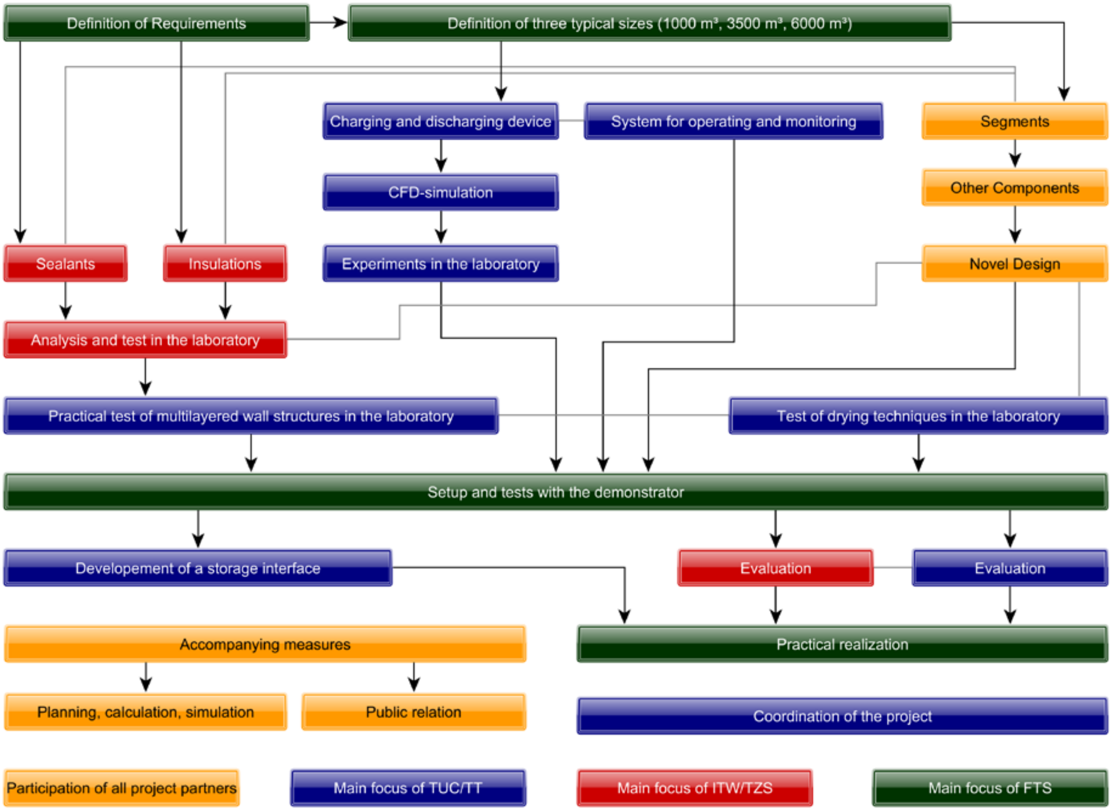

Fig. 4: Overview of the division of work and the procedure in the project, Urbaneck et al. 2016b

Figure 5: Test rig for practical testing of multi-layered wall structures in Chemnitz, enamelled and sealed wall segment (left), pivoting wall cut-out with thermal insulation and cladding panel in the vertical position during the test (right)

Fig. 6 to 8 shows the segmental wall construction, the thermal insulation of the floating device as well as the charging devices in an early state of construction. Fig. 9 presents the final construction of the demonstrator.

After filling the tank and performing first charging tests with hot water, it appears that

- the sealed wall construction is watertight (leakage tests successful),
- the floating ceiling and the flexible sealing work as expected and
- a high stratification quality can be achieved (hot water tests successful).

Figure 6: Demonstrator in Nortorf, Germany (left), approx. 100 m³, single-zone storage tank, test of different coatings, interior view (right), April 2016

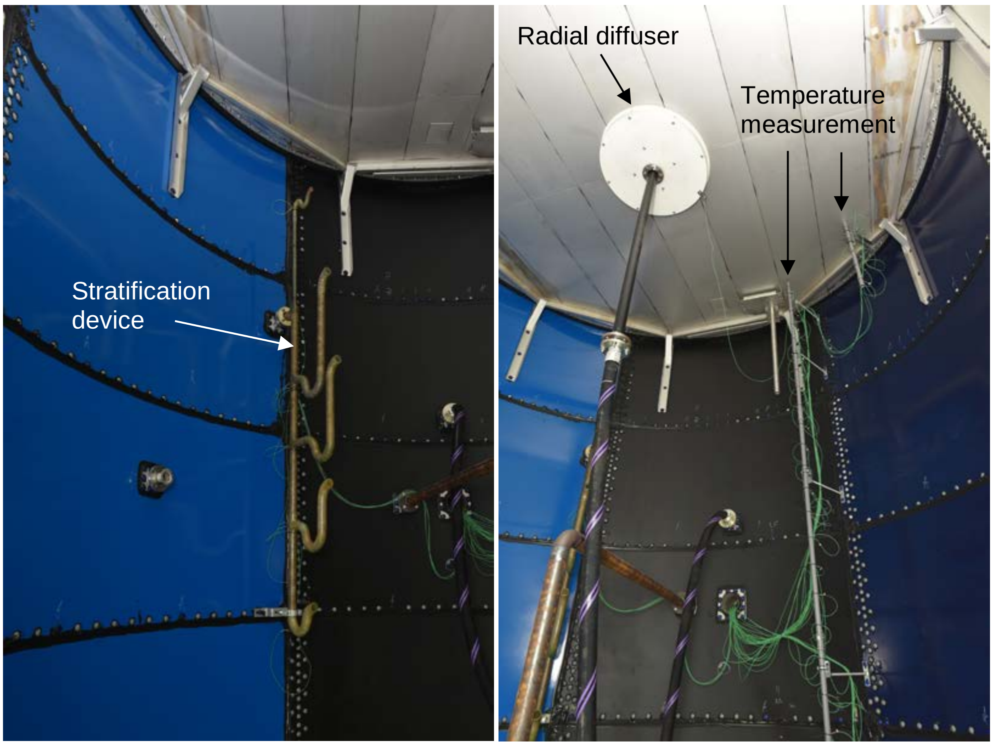

Figure 7: Stratification device (left), radial diffuser with flexible EPDM-hose and temperature measurement probes (right), February 2017

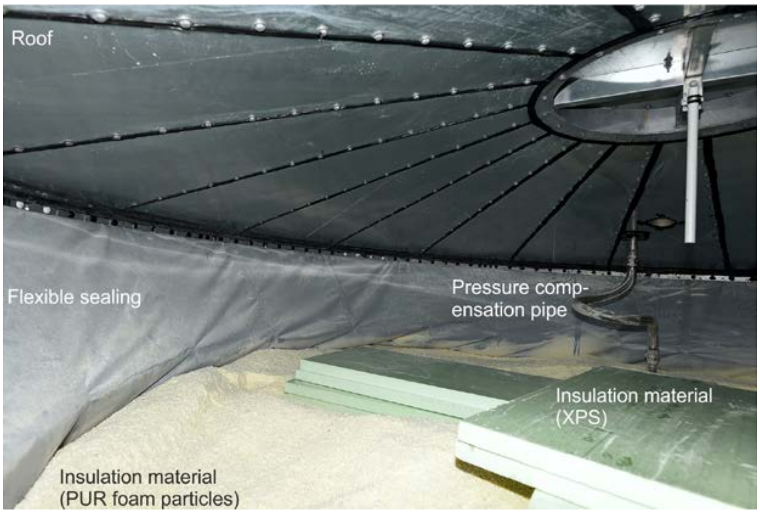

Figure 8: Laying of XPS panels on the PUR foam of the floating ceiling in the attic during the construction, July 2017

Figure 9: CAD-Visualization (left), panelling with trapezoidal sheet metal (right), July 2017

4. Conclusion and Outlook

A project for the development of a novel thermal energy storage tank type with a floating ceiling was presented. The design has multiple advantages. Besides a very efficient thermal insulation at the top of the tank it ensures protection of the thermal insulation by avoiding practical problems like moisture penetration. The simple design provides significant benefits compared to other storage types. However, because of the thin-walled construction and the project objectives, the wall structure as well as installations and peripherals need further research and development. The direct integration of solar thermal systems is intended. By now, the construction process is finished. First tests showed, that the design is suitable to operate as an aboveground hot water store in segmental construction for solar and district heating systems. Ongoing work is focused on tests regarding stratification quality and external heat losses.

5. Acknowledgement

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