Development of a Cost-Efficient Buried Hot Water Storage – Concept and First Results

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Abstract

Ground buried hot water storage tanks overcome the spatial limitations of an indoor installation. Larger storage volumes can be chosen in order to increase the solar fractions of the heating demand. The paper presents the tasks and aims of a research project[1] in which a buried storage is developed, consisting of a concrete cistern, a XPS insulation and an inliner foil combining EPDM and aluminium. The storage operates under atmospheric pressure. During the prototypes construction and implementation, first experiences regarding methods of manufacturing and installation efforts have been gained. A large number of sensors has been installed for surveying long-term properties and the thermal performance of the storage. For the 5.5 m³ prototype a heat loss rate of about 5 W/K has been measured, corresponding to a temperature decrease of approximately 1 K/d when cooling down from 85 to 65°C. An important task beside the tank and heat exchanger design is the development of a new insulation material based on enhanced polystyrene foam, which shall have a long term reliability at temperatures up to 95°C.

1. Introduction

In single- and multi-family-houses large thermal storage tanks are required to increase the solar fraction of the total heat demand. Up to now, storages in general are installed within the building, mostly in the basement. Here, low ceilings and small access ways limit the possible solutions for large volume storages. They may either be custom-made or interconnected in cascades of several industrial tank modules which cause higher heat losses in consequence of a larger surface [1]. Both of these solutions require indoor space and need to be individually designed.

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[1] The project with the title „Solarthermie2000plus: Neuartiges Konzept für kosteneffiziente erdvergrabene Heißwasserspeicher" (KES, New concept for cost efficient soil buried hot water tanks), FKZ 0325950, is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Therefore the authors are working on a project which is targeted to the development of a soil buried thermal storage tank placed close to the building, thus overcoming the restrictions of installation space. Furthermore, the storage shall be implemented as cost-efficient as possible to compete economically with conventional concepts. Within the research project a completely new storage concept will be developed and evaluated whereas the thermal interaction between storage tank and surrounding soil will be determined as well as the optimized integration into solar assisted heat supply systems. Furthermore a new foam insulation with high long-term stability at high temperatures will be developed as well as immersed heat exchangers based on flexible corrugated tubes.

Fig. 1: Installation of the first storage tank test sample at the ISFH test area.
Outer height 3.15 m, outer diameter 2.74 m, water volume 5.5 m³

2. Storage Concept

To provide a most cost-effective storage with a constantly high quality, it is advantageous to limit the installation work on site to a minimum. Except of the excavation and refilling of the pit and the installation of the pipes, no further work should be necessary at the construction area. In consequence to that, the tank construction should be completely finished before delivery.

The main components of the storage are a cylindrical concrete cistern as outer envelope, a thermal insulation based on expanded foam placed inside the tank and a compound diffusion barrier foil serving as inliner bag, which contains the storage water. Charging and discharging will be managed by a set of immersed heat exchangers made of flexible corrugated tubes. The storage concept is shown in Fig. 2.

In addition to the first prototype developed within the project, a second thermal storage tank developed by the company Mall is tested. Instead of using a foil the storage has a solid tank made of stainless steel and a packed bed of expanded glass particles instead of XPS.

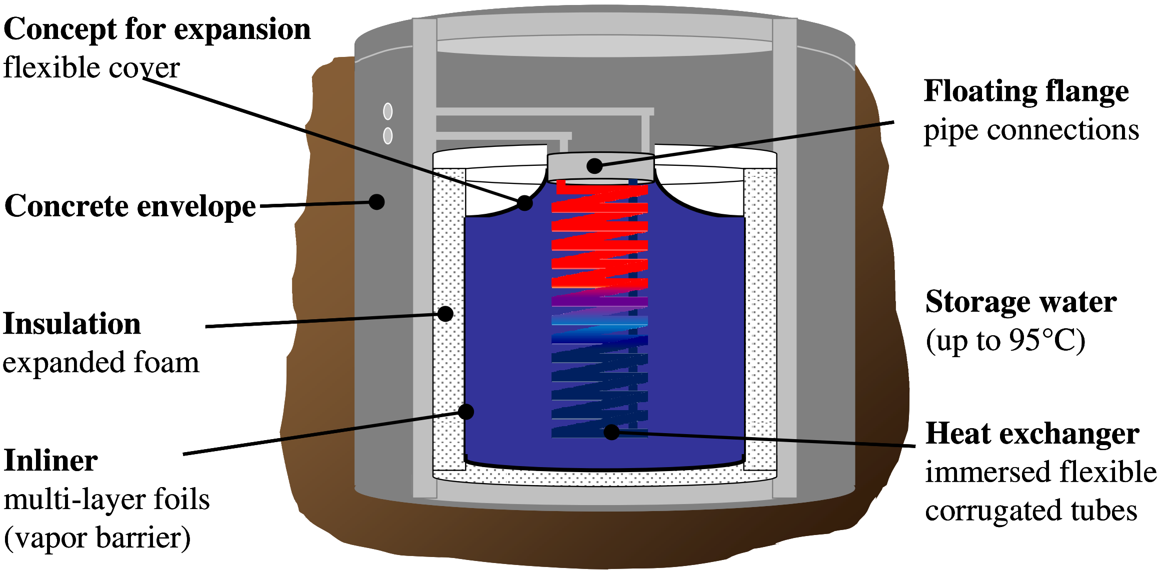

Fig. 2: Sketch of the storage concept

2.1 Concrete Cistern

The envelope of the storage is a cylindrical concrete cistern developed by the company Mall, derived from a construction for the collection of rain water. The cistern has been tried and tested as buried water tank for years now and provides protection regarding mechanical stresses appearing during the implementation and operation. The seamless construction of the concrete component preserves leakage through gaps and points of attachment. The design and the technique of construction was adjusted to the requirements of the heat storage tank.

2.2. Insulation

The thermal insulation layer of the storage consists of extruded foam sheets placed inside the concrete envelope. To locate the insulation layer outside has been considered as unfeasible, because damages may occur during transport and installation and the insulation material had to be protected against water in the ground. The concept of construction admits the application of panels.

EPS (expanded polystyrene) and XPS (extruded polystyrene) are qualified insulation materials. Due to the mechanical load resulting from an expected maximum water column of 5 m, XPS has been chosen. However, standard XPS only withstands temperatures below 75°C for a long-term without degradation. In consequence to that, the research project includes the development of a temperature resistant insulation material basing on XPS which shows a long-term reliability against temperatures of up to 100°C. This development is conducted by the partner BASF SE.

The insulation panels of the first prototype are clamped to the storage concrete wall as to be seen in Fig. 3. Due to a panel thickness of 3 cm, which is the actual state of the development, the installation procedure has been proven to be simple and shows a minimum amount of thermal bridges.

Fig. 3: Built-in and clamped XPS panels of the prototypes storage jacket. The insulation of the mantle consists of 6 panel layers forming an overall thickness of 18 cm.

2.2 Inliner foil

The inliner foil contains the storage water and prevents water penetration into the insulation. Furthermore the inliner has to prevent the diffusion of water vapour trough the foil to eliminate an enrichment of moisture inside of the insulation layer. Therefore, a foil with a high resistance against water vapour diffusion even at high temperatures is essential. A further requirement is the long-term reliability against temperatures up to 95°C. Finally, the inliner foil is foreseen to compensate the thermal enlargement of the water volume by expanding elastically. This design principle makes further complicate and susceptible periphery for expansion compensation unnecessary, which is important for the underground outdoor installation (low pressure, danger of freezing).

To comply with all the requirements mentioned above the inliner for the first prototype will initially consist of two separate foil layers of an EPDM bag (ethylene propylene diene M-class rubber) and a PE-aluminium-HDPE (high density polyethylene) compound foil (see Fig. 4). The bag made of EPDM contains the storage water and is temperature-resistant up to 100°C. It has been implemented according to the concept of an integrated volume expansion with a moving coverage. In case of high temperature the top of the EPDM bag will move upwards. Therefore, the connection head will follow the movement of the EPDM-foil when water density is changing. The second bag is made of an aluminium compound barrier foil, which wraps the EPDM bag. It prevents the diffusion of water vapour but is not exposed to mechanical stresses.

Further efforts are targeted towards the development of a single foil bag incorporating the required features. This would simplify the assembling of a storage tank and reduces the costs. Therefore tests of different foils with regard to temperature, water vapour diffusion resistance, mechanical stress and expected life time are designated. Fatigue failures under repeated bending stress, the influence of connection methods, and further practical questions are in focus of this work, which is done in cooperation with the University of Applied Sciences in Osnabrück.

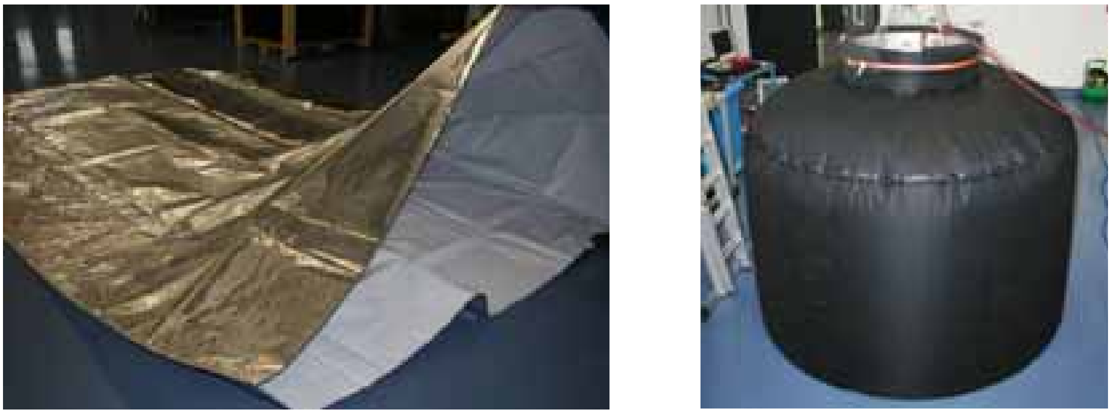

Fig. 4: Foil bags forming the inliner of the first prototype storage, aluminium compound foil (left) and EPDM bag (right)

2.3 Heat exchangers

Within the framework of the project corrugated tubes are discussed for the use of immersed heat exchangers and a buried piping to access the storage tank from the building. Although their use as heat exchangers has become common, there is still a lack in the quantification of heat transfer capability, especially if different geometries of tube corrugation are used. Therefore heat transfer properties are investigated in different test facilities, using specially corrugated tubes of various tube geometries and various spiral coil geometries. These evaluations play a key role to scale up the heat exchangers of the prototype storage tank. The criteria are to minimize the material demand with regard to the heat transfer performance.

2.4 Simulations

A further part of the research project is the simulation of buried storage tanks in heat supply systems of single- and multi-family houses. The simulations are based on the TRNSYS IEA Task 32 system [2] with the storage type 340 [3]. The heat supply system has been changed to fit the necessities of a storage at atmospheric pressure while the load side remains unchanged. In addition, the storage type has been extended with an interface connecting storage and surrounding ground. The implemented simulation systems will subsequently be validated by a comparison with measurements of the first prototype.

2.5 Measurements

The buried storage prototype will be surveyed extensively. The measurement system therefore includes temperature sensors in the storage water and temperature and moisture sensors inside the tank and the insulation material. The temperature and moisture of the surrounding soil will also be monitored. The tests will partly refer to the storage testing standard EN 12977-3 [4] which enable the comparison of storage performance parameters with those of conventional hot water tanks. Besides the determination of the heat losses the usability and performance of the storage concept will be of special interest. Long-term studies will be focussed on insulation behaviour regarding e.g. moisture penetration and the associated risk of higher heat losses as well as the interaction between storage and surrounding soil during continuous operation.

2.5.1 Measurement of heat losses

First measurements of the standby heat losses have been finished. Therefore, the buried storage has been operated in standby mode for 500 hours after being heated up to an overall temperature of 85°C. Fig. 5 shows the progress of cooling during standby operation, including the beginning of stratification in the bottom layers. During the period of standby, the average water temperature decreases by about 1 K/d.

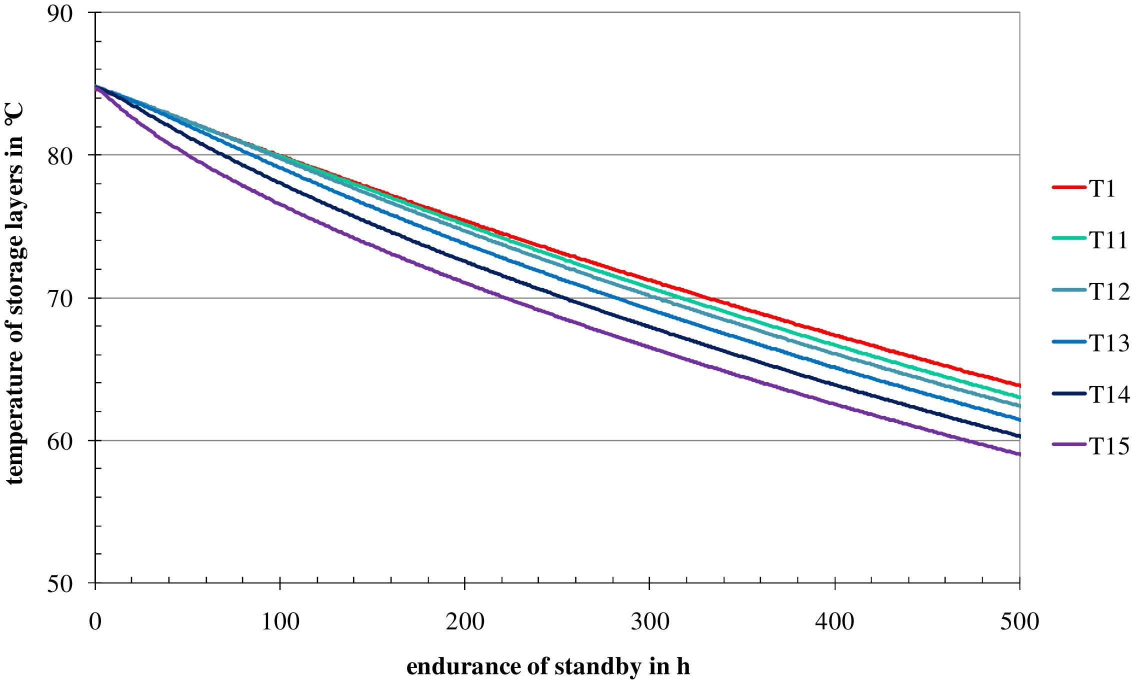

Fig. 5: Cooling of the buried storage during standby for a time of 500 hours
Note, that only the highest layer T1 and the five lowest layers (T11…T15) are shown.

The heat loss rate is determined by the decrease of inner energy of the water, divided by the appropriately determined average temperature difference and time. Contrary to storage tanks installed above surface, buried storages are surrounded by soil. Due to this the surrounding temperature of the soil depends significantly on the vertical position, the seasonal variation and the heat losses of the storage. Therefore the ground temperatures are measured near the outer storage envelope in several depths below surface. The heat loss rate was thus calculated with a special approach which regards surface-weighted temperature differences for the top, bottom and jacket sections. Based on this the heat loss rate for the standby mode has been determined to 5 W/K.

References

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