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INNOVATIONS IN PIT THERMAL ENERGY STORAGES FOR DISTRICT HEATING NETWORKS

Summary

The next generation of Pit Thermal Energy Storages (PTES) shall permanently meet the requirements of the European district heating industry. The project therefore focuses on advancing materials for higher long-term durability at storage temperatures of 95 °C, developing cost-effective construction and operation methods, ensuring well-functioning and long-lasting floating covers, enabling reliable and simple operation monitoring, and supporting market deployment through simulation models and simplified tools.

Keywords: PTES, Thermal Energy Storage, PERT geosynthetics barriers, construction methods, monitoring, CFD, FEM-Simulation, fiber optics

Field of application: Knowledge transfer, planning support, material and design development, fundamental research

Addressed audience: district heating network operators, municipal utilities, industry, research institutions

1. Introduction

Experts estimate that Germany will need seasonal heat storage capacity of 10 TWh in 2045 to decarbonize district heating networks. This corresponds to over 600 large water storages, each with a capacity of 200,000 m³, and indicates a strong market potential and a significant scaling-up of storage technologies in the coming years [1]. Pit Thermal Energy Storages (PTES) offer a cost-effective solution for short- and long-term heat storage. Their simple design and scalability make them attractive for widespread use in new and existing heating networks. Depending on the application and integration, PTES can reach volumes of 100 m³ to 200,000 m³. Europe hosts a growing number of PTES, with Denmark leading in operational installations and several projects underway in countries like Germany, Austria, France, and Serbia.

Despite extensive operational experience, several technical and scientific challenges remain, including the long-term durability of materials at temperatures up to 95°C, optimization of the floating lid regarding vapor transmission, stability and detection of leaks. The project addresses these challenges with the goal of developing a new generation of PTES that meets the long-term requirements of the European district heating industry.

Fig. 1: Completed PTES laboratories with storage volumes of 2.000 m³ (left) and 3.000 m³ (right), 11/2025

2. Innovations in PTES construction

With the construction of a storage laboratory with two PTES (2,000 and 3,000 m³), the project partners have a unique opportunity to test new construction methods. The laboratory PTES has been finished in 2025 and started charging in February 2026 with industrial waste heat in Germany, see Fig. 1. Not only scientific measurement, but also practicality in construction and the scalability of new construction methods and innovations are at the forefront of the project and are set to shape the next generation of PTES. The following innovations have been implemented for this purpose:

Steep embankment with soil with 34° (southern pit) and reinforced soil with 70° (northern pit):
The scalability of PTES is limited by the use of surface area due to flat embankment angles. For the first time, a PTES with a 70° embankment angle has been realized using an innovative construction method with reinforced soil. In this case, the volume can be increased from 2,000 m³ (southern pit) to 3,000 m³ (northern pit) with the same surface area. This construction method could be particularly relevant for large-volume storages in densely populated urban areas.

High-temperature resistant polyethylene (PERT) materials development for a long lifetime
A lifetime of PTES of at least 20 years is necessary for an economical operation. A crucial part of this is the sealing system of the PTES especially the geomembrane. Therefore, a new PERT geomembrane and additional geonet as part of the used protection layer of the sealing system has been developed that is designed to withstand the requirements of long-term use at 95°C. Both materials as geomembrane and protection layer has been installed in the laboratory PTES. Extensive laboratory tests on aging, long-term stability and for the geomembrane on water vapor diffusion behavior have been carried out.

Pipe penetration structures made of polyethylene:
Complex concrete structures are often constructed to penetrate the connection pipe to the storage. Here, prefabricated polymer parts were used for the first time for the pipe penetration structures. These can be easily inserted into the embankment and filled with concrete on site. This offers significant potential for cost and time savings.

New design concepts for insulated wall structures
In existing large-scale PTES, side wall insulation is usually not used. However, side wall insulation can increase the storage efficiency and can be necessary where the surrounding subsoil must not be heated up, for example in dense urban areas. Four different wall insulation structures made of polyurethan and foamed glass insulation were implemented for this purpose. These are thermally evaluated under real conditions with a comprehensive monitoring concept, see section 3.

Avoiding corrosion problems of built-in components:
Another major cost factor is the complex treatment of the storage water. Treatment is normally necessary to avoid corrosion at high temperatures in the charging equipment and the pipes, which are often made of black steel. In the laboratory storages, diffusers and connecting pipes are made of polypropylene to eliminate costly and time-consuming water treatment.

Integration of a distributing-temperature-sensing (DTS) leak detection system:
Leakage monitoring is necessary to ensure safe operation of the PTES. A Raman DTS system with hybrid heating function is used for leakage detection. The system can locate leaks in conventional water storages with an accuracy of centimeters. This was the first time a DTS system was used in the context of PTES, see Fig. 2. The relative temperature change is measured along the cable, enabling not only leak detection but also the creation of a high-resolution temperature profile of the storage walls, bottom, and lid. Devices for an artificial leak test were installed in the storage. During operation, artificial leaks are to be simulated to test the functionality of the system.

3. Scientific evaluation and development of new tools for planning support

To evaluate the materials and construction innovations under real conditions a comprehensive measurement concept with 175 sensors was developed and implemented in the laboratory PTES. Ten PT100 sensors on different height positions and heat flux sensors were installed in each storage wall to evaluate different insulation materials. Individual walls were equipped with special measurement technology to investigate specific correlations and effects between the subsoil and the storage. For example, specific soil-moisture and heat-flux measurement technology were installed to investigate moisture and heat transport processes in the ground and the drying behaviour of the embankment during operation. Simulation models in FeFlow and TRNSYS are using the measurement data listed above. This allows thermal interactions with the subsoil to be analysed at an early stage and appropriate actions to be taken during the planning phase of new PTES.

Another key element of the project is the measurement of different insulation materials and lid constructions with regard to heat-coupled mass transport. One of the two lid constructions was divided into four segments, each segment contains a spatially separated measuring field in which extensive moisture, temperature, and heat flux measurement devices are installed. Initial humidity conditions can be precisely preset in the measuring fields. Aim of the investigation is to validate a calculation tool developed for the heat-coupled mass transport to better predict possible moisture accumulation and associated heat losses in future lid constructions.

A total of 13 fiber optic temperature measurement probes were installed on and around one diffuser, see Fig. 2. The measurement technology involves fiber optic temperature measurement based on Rayleigh scattering. This allows temperature measurements of the inflowing water at the diffuser to be resolved with millimeter precision. This means that asymmetries and the mixing behavior of the diffuser can be examined for the first time in real operation conditions. Existing CFD models are to be validated using the generated data.

Fig. 2: Two different fiber optic systems in the context of PTES. Left: High resolution temperature measurement with Rayleigh-scattering. Right: Leak-detection monitoring with a hybrid fiber optic cable with a Raman-scattering.

4. Expected results

The completion of the laboratory storages yielded important insights gained from the innovations described above. A deeper insight into the construction phase and the associated challenges will be presented at the conference. The focus will be on the relevance and transferability for industry as well as the scalability of the innovations.

With the start of charging the laboratory storages in February 2026, the measurement data recording began. A comprehensive measurement campaign is planned to be examined in March 2026. Results are going to be expected by May 2026. The first scientific evaluations and initial assessments of the above-mentioned innovations will be presented at the conference.

5. References

[1] Agora Energiewende, Prognos, GEF, "Wärmenetze – klimaneutral, wirtschaftlich und bezahlbar. Wie kann ein zukunftssicherer Business Case aussehen?", 2024. [Online]. https://www.agora-energiewende.de/fileadmin/Projekte/2023/2023-18_DE_Business_Case_Waermenetze/A-EW_335_Businesscase_Waermenetze_WEB.pdf

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