Solar assisted district heating system with seasonal thermal energy storage in Eggenstein-Leopoldshafen

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Abstract

The solar assisted district heating system with seasonal thermal energy storage in Eggenstein-Leopoldshafen (Germany) is the first system realized with existing renovated buildings. The system consists of 1600 m² flat plate collectors and a 4500 m³ gravel-water thermal energy store (TES) for seasonal thermal storage. Experiences gained within the BMU-project "Further development of the pit heat store technology" contributed to the design of the seasonal TES. This paper focuses on the design and construction of the gravel-water store. The monitoring concept of the solar assisted district heating system with focus on the gravel-water TES is presented.

1. Solar assisted district heating system

The solar assisted district heating system with seasonal thermal energy storage in Eggenstein-Leopoldshafen (Germany) is the first system realized with existing renovated buildings. The project was initiated by a major refurbishment of the school, the gym and the existing district heating system. An additional gym with shed roof carrying 600 m² of flat plate collectors (FC) was built. Together with a public swimming pool and a fire station the district heating system consists of buildings with a gross building area of 12 000 m². For seasonal thermal storage of the solar heat produced by 1 600 m² of flat plate collectors a 4 500 m³ gravel-water thermal energy store (TES) is integrated into the district heating system, see Fig. 1.

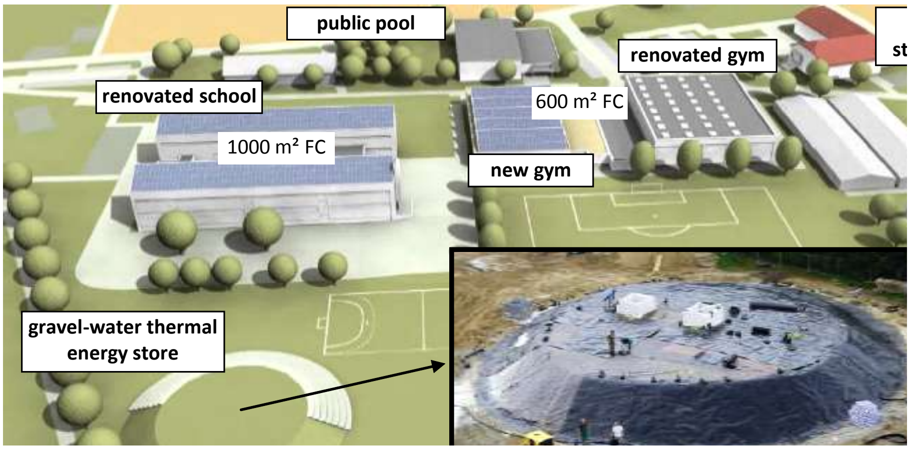

Fig. 1: Solar assisted district heating system with 1600 m² flat plate collectors and seasonal storage in Eggenstein-Leopoldshafen (Germany)

For backup heating two 600 kW gas boilers and a 30 m³ buffer store are available. Discharging of the seasonal TES down to 10 °C is facilitated by the use of a heat pump with a thermal power of 60 kW. Thus, the thermal capacity of the store is increased by 75% compared to discharging of the heat store to a return temperature of the heating net of 40 °C.

A detailed description of the system concept is given in [1]. Furthermore, optimization of the solar assisted district heating system by means of TRNSYS simulations is presented in [2]. This paper focuses on the design and construction of the gravel-water store and the measurement concept of the system.

2. Store construction

2.1 General aspects

For seasonal storage of thermal energy several concepts have been realized within the last 30 years, see Fig. 2. At least one of each concept has been realized in Germany. Pit TES are constructed without further static means by mounting insulation and a liner in a pit. According to their storage medium seasonal pit TES are distinguished into gravel-water (GW) TES, soil/sand-water TES (SW) or hot water TES.

The hot water (pit) TES is preferable over the gravel-water TES in terms of thermal capacity and operation characteristics. Due to the improved dynamic behaviour compared to the other seasonal TES types, the integration of a hot water TES into the heating system is less problematic, i.e. no additional buffer store is required. In case of leakage, a hot water store may be repaired, whereas - depending on required maintenance and repair - it may be more economic to build a new gravel-water pit TES instead of repairing it.

Gravel- or soil/sand-water TES are only advantageous, if static concerns are of major importance as in the case of the gravel-water TES in Chemnitz, where a parking lot has been built on top of the store. A cover for a hot water TES with comparable static characteristics requires enormous technical and financial efforts. For hot water stores three types of covers may be distinguished, namely self-supporting (shell shaped) covers, supported covers and floating covers, see [3], [4].

For optical reasons, seasonal TES are buried or at least partially buried. Integration into the landscape is of major importance especially as in most cases a seasonal TES will be located within or close to residential areas. Several disadvantages result from the construction below surface level. First of all additional costs arise for the excavation. Secondly, due to the soil pressure, the static requirements are more complex. Furthermore, a construction in moist soil requires measures that prevent the insulation from getting wet. Above ground, a construction with rear ventilation would be a possible solution.

Buried TES may be constructed as cuboids, cylinders, as inversed (and truncated) pyramids or cones or as a combination of one of these geometries. Minimization of thermal losses requires optimization of the area to volume ratio. Additionally, an aspect-ratio of $h/d = 1$ should be aimed for seasonal storage.

The geometry of tank TES, constructed with in-situ concrete or with prefabricated elements, is more flexible than that of pit TES. The pit geometry is restricted to certain slope angles depending on the friction coefficient of the soil. Furthermore, the depth of the pit may be limited due to ground water. Steeper slopes or construction in ground water can be realized by applying special geotechnical works, such as sheet wall or bore pile wall. Earth works, however, contribute significantly to the total construction costs.

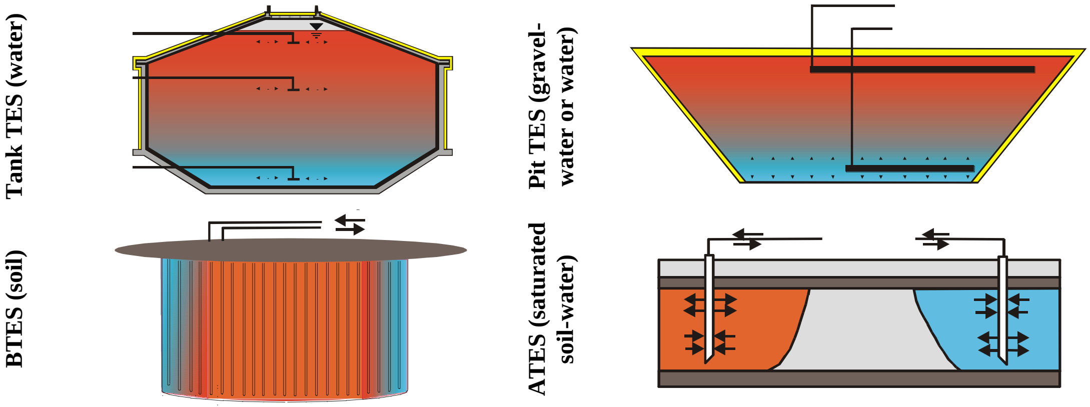

Fig. 2: Seasonal thermal energy stores: tank, pit, borehole (B) and aquifer (A)

The decision for a certain concept depends on the geological and hydrological conditions in the bedrock of the respective location. Eventually the costs have to be minimized. For the determination of the costs, transient system simulations are required.

The wall of a buried TES is an assembly of several layers. The complexity of the design of such a composite wall arises due to the fact that the envelope has to guarantee protection of the thermal insulation from moisture penetration. Desiccation must be possible for the case the thermal insulation becomes wet.

The envelope of a buried seasonal TES is a composite consisting of several layers. The most important components are the liner with or without vapour barrier and the thermal insulation (see Fig. 3). Furthermore, several geosynthetics such as geogrid, geonet, drainage grid and (protective) fleece are part of the envelope.

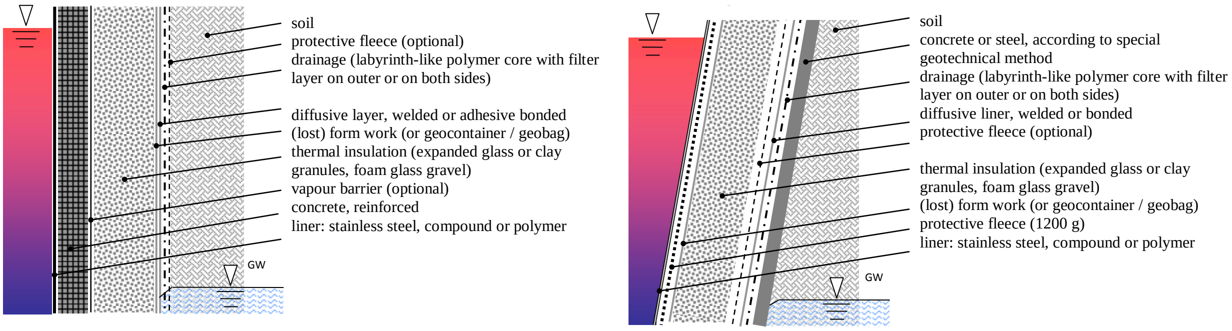

Fig. 3. Multilayered (composite) wall of a seasonal TES, left: tank, insulation inside with respect to the concrete/steel structure; right: pit, insulation outside with respect to concrete/steel, GW: ground water

On the present market high temperature (>80°C) liner materials are not available. Hence, standard geomembranes known e.g. from landfill constructions had to be used for the lining of the store. Several materials were utilized as liner. The most common are (stainless) steel, polymers such as polyolefines (HDPE, LDPE, PP) and elastomers (EPDM, IIR). But also bitumen, clay, resin, high performance concrete and asphalt were considered and/or applied in research and pilot projects.

The majority of the tank TES are sealed with (stainless) steel liners, which are advantageous with respect to temperature resistance, aging and permeation resistance, but have the highest costs. Only the very first Swedish stores, Studsvik and Lombohov, and the TES in Lisse have elastomeric (IIR) or polymeric liner (HDPE), respectively. The majority of the pit TES were sealed with HDPE liners, but also PP, EPDM and TPE were applied.

Table 1. Lining of pilot and research TES, see [3]

Liner	Tank (11)	Pit (20)
stainless steel (10)	6	4
geomembrane (16)	3	13
others (clay, bentonite, waterproof concrete) (5)	2	3

Due to the required pressure resistance and temperature resistance (up to 95°C), the application of polymeric insulation materials is limited, nevertheless it was applied in several projects.

Whereas in earlier projects, such as in Lombohov (S), Vaulruz (CH), Friedrichshafen (D), Chemnitz (D) or Sjökulla (FN) sheets of rock or mineral wool, polyurethane (PUR), extruded (XPS) or expanded (EPS) polystyrene were installed at the side walls and on the cover, the more recent TES such as in Hannover (D), Steinfurt-Borghorst (D), Munich (D) or Eggenstein-Leopoldshafen (D) are insulated with bulk insulation material i.e. expanded glass granules or foam glass gravel.

Table 2: Thermal insulation of pilot and research TES, see [3]

XPS	Vaulruz, Lyngby, Neckarsulm, Chemnitz, Augsburg, Attenkichen
EPS	Marstal (HW), Rottweil, Egenhausen
PUR	Ottrupgaard, Sjökulla, Herlev, Växjö, Lombohov, Studsvik, Illmenau, Stuttgart (lab),
Mineral-/rockwool	Särö, Rottweil, Friedrichshafen, Sjökulla, Lyngby, Marstal (HW)
Foam glass	Berlin, Lisse, Augsburg
Lava Stone	Stuttgart (GW)
Expanded Clay	Lombohov
Expanded glass	Steinfurt, Hannover, Stuttgart (lab), Crailsheim, München, Eggenstein
Foam glass gravel	Stuttgart (lab), Munich, Eggenstein, Crailsheim (Buffer + BTES)

Particularly for large TES (~2000 m³), installation of bulk material by pouring or by air-injecting from silo trucks (see Fig. 4) is much more effective with regard to costs and time than mounting insulation sheets or plates. This is particularly true if costs for scaffolding can be avoided.

Depending on insulation material, operational mode and local boundary conditions, the insulation is built in layers with a thickness of up to 1 m. The thermal resistence of porous materials decreases with increasing moisture content and temperature. Already for dry insulation materials an increase of 30 % of the thermal conductivity at a temperature of 80 °C compared to 20 °C can be observed. This effect is more pronounced with wet insulation, see [5].


source: ITW

source: ITW

SNAB,
München-Ackermannbogen
source: Solites

Fig. 4: Bulk insulation material in membrane-formwork with diffusible liner

2.2 Design of the gravel-water thermal energy store

With regard to the construction of the seasonal TES in Eggenstein several boundary conditions had to be considered. As the ground water level is only 7.5 m below top ground surface, the store had to be constructed in such a way that even in the case of a hundred year flood, the thermal insulation is protected from penetration of ground water. Hence, an external HDPE liner for ground water protection was installed.

Fig. 5: Construction of the gravel-water pit TES

A further limiting boundary condition is that the store is located in the area of a schoolyard. Unrestricted accessibility for the pupils and also trafficability was demanded by the customer. Obviously, a 100% safe construction - even in the case of a total failure of the liner - was required. Therefore, a concept with a gravel-water store was favoured over a hot water store.

The geometry of the store consists of two truncated cones, see Fig. 5. 2/3 of the volume of the store is located below ground surface. It is filled with 16-32 mm gravel to a height of 2.5 m. In the remaining volume the excaveted gravel/sand is refilled in order to reduce construction costs. The upper 1/3 of the store is formed as an truncated cone with washed 16-32 mm gravel. Charging and discharging of the gravel-water TES is realized by two vertical wells. One is embedded in the bottom gravel layer, the other in the top gravel layer.

An inverted truncated cone with a height of 7 m and a diameter of 35 m was excavated. The maximum possible slope at the site (sand and gravel) is 35°. After installation of the liner and the thermal insulation, the store was filled with washed gravel and with part of the excavated soil in order to save costs for the gravel. To prevent elutriation of fine particles, the 2 m high soil layer was packed into geotextile fleece. The second truncated cone was formed on top of the ground surface with washed gravel with a height of 2 m and a slope of 26°.

The internal liner consists of of a HDPE membrane with vapor barrier. The aluminum layer prevents water vapour diffusion and thus protects the thermal insulation from getting wet during the entire period of operation of more than 30 years. On the present market high temperature liner materials are not available. Hence, standard geomembranes known from landfill constructions had to be used for the lining of the store. Reliable information about service lifetime of polymer liners under operation conditions of a seasonal TES is not available. Therefore, the maximum operation temperature of the store is limited to 80 °C.

Due to the situation that the ground water level is only some centimeters below the store, special attention was drawn to the design of the store with respect to insulation type and thickness. Simulations conducted by ITW and Solites yielded that an increased insulation thickness at the bottom is required. Hence, on bottom and on side walls below top ground surface 50 cm expanded glass granules was suggested. Above top ground surface 90 cm foam glass gravel form the insulation on side walls and at the top of the store. Both, foam glass gravel and expanded glass granules are pressure resistant in the required range. Foam glass gravel was favoured over expanded glass granules for the upper part as it is shapeable due to its relatively high friction angle. The resulting dimensions of the insulation corresponds to the economic optimum with regard to the material and installation costs within the limits of the available budget.

Fig. 6: Primary and secondary chambers, installation of the insulation by blowing from silo-truck into chambers or loose; lower left: installation of the foam glass gravel by pouring from big bags. It is delivered by trucks and filled on-site into the big bag by a front loader, lower right: filled and evacuated chamber.

In order to protect the insulation from getting wet an external liner for ground water protection was installed. The external liner and the internal barrier liner are welded together such that they form chambers, which are filled with the bulk insulation material. In total 30 primary and secondary chambers were built, see Fig. 6.

Based on a method tested in Steinfurt-Borghorst [6] a leakage detection system was established using these chambers. Preliminary tests were carried out in the framework of the R&D project “Further development of pit heat stores” at ITW [4]. As the tests showed good results the evacuation system was established. After filling the 30 chambers with the insulation they were hermetically sealed by hot air and extrusion welding technique and evacuated to roughly 0.5 bar. This procedure enables leakage detection during construction and if desired also during operation.

For future projects with gravel-water store such an evacuation system is recommended. However, it is recommended that state-of-the-art vacuum equipment is applied and that a warning system signals in case of increasing pressure.

3. Monitoring

In the heating central heat flow meters are installed in every circuit. Additional temperature sensors allow for measurement of flow and return temperatures to or from buffer store (B), heat pump (HP) and vessel (V), see Fig. 8. At the heat exchanger between the circuit of the store and the collector field anti-fouling units are installed. The effectiveness of the anti-fouling device is determined by monitoring the heat transfer coefficient (UA) of two identical heat exchangers, one with and one without the anti-fouling electrode. A meteorological station allows the monitoring of the ambient temperature, the irradiation, and wind velocity.

The store and the surrounding soil are equipped with several Pt100 temperature sensors, see Fig. 9. Additionally, heat flux sensors are placed at several locations in the envelope of the store in order to determine the local thermal losses. The hydraulic behaviour at charging and discharging via the two wells with regard to vertical and horizontal stratification will be one of several investigations. CFD simulations will be conducted in order to be able to improve the concept furthe.

Special attention needs to be paid to the situation that the ground water level is just below the store. Increased thermal losses in comparison to locations without ground water are expected. Hence, one focus of the monitoring will be the determination of the effect of ground water (flow) on the thermal losses. Ground water level, temperature, flow velocity and direction will be additionally monitored. Three wells will be installed that allow for the continuous determination of ground water velocity, level and temperature. A thermal response test is planed in order to determine the soil properties (thermal conductivity, thermal diffusivity).

4. Outlook

The system is designed to achieve a solar fraction of 35 to 40 % of the total heat demand. This corresponds to a yearly reduction of 390 tons of CO_2 emission. Compared to the original situation (without refurbishment) energy savings of 65 % will be achieved. Operation of the system is planned to begin in summer 2008.

On the one hand detailed investigations such as on the hydraulic behaviour of the store or concerning the influence of ground water on the thermal losses will be carried out. On the other hand an energetic analysis of the entire system including the performance of the heat pump will be conducted.

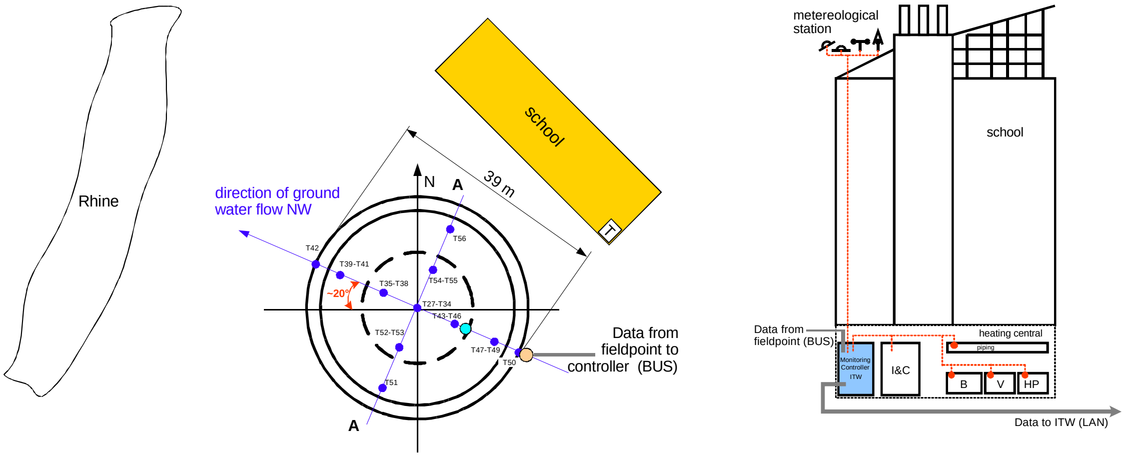

Fig. 8: Position of the TES with respect to the river Rhine and direction of the ground water flow; heating central and measurement system in the school with buffer (B), gas vessels (V) and 60 KW heat pump (HP)

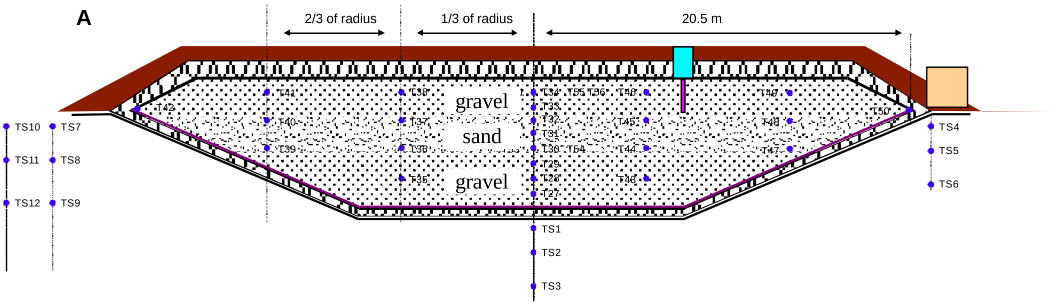

Fig. 9: Cross section of the GW-TES, location of temperature sensors in the store and in the surrounding soil

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