Projektinfo **14**/2014

Detailed information on energy research

Vacuum tank stores heat

Perlite powder in storage tank wall reduces heat losses

BINE
Information Service

An efficient long-term heat storage tank boosts the shares of fraction of solar thermal energy systems in buildings. Staff at Bavarian Center for Applied Energy Research and at steel and metal engineering company Hummelsberger have developed a storage system that minimises thermal losses and optimises temperature stratification. A vacuum between the inner and outer tank combined with a perlite powder filling reduces the thermal conductivity of the storage tank shell. The long-term heat storage tank is already being used for heat supply in single-family homes and apartment buildings.

The vacuum super-insulated (VSI) tank can store supplied heat over several weeks or even months. The technology allows high solar shares of fraction in existing small and medium-sized buildings. To achieve such returns, buildings heated by solar power should possess low-energy house standard as a minimum requirement. The intermediate storage of district heat or industrial process heat at 100 °C to 200 °C represents a further area of application for VSI tanks. The technology was initially developed through three progressively enhanced prototypes at Bavarian Center for Applied Energy Research (ZAE Bayern). The storage tanks were constructed and installed by company Hummelsberger. For this type of storage, volumetric capacities of 5 to 50 cubic metres are currently possible. For future applications, the researchers are planning to develop modularly structured storage tanks that can hold in excess of 100 cubic metres.

The aim of the project was to minimise heat losses by the storage tank. To achieve this objective, the project's members resorted to a principle that has been employed for many years in cryogenics for the storage of cold temperatures, including by Hummelsberger. The company manufacturers outer shells for double-walled cryotanks and places the perlite-filled cavity under vacuum. Containers of this nature

This research project is funded by the

Federal Ministry for Economic Affairs and Energy (BMWi)

are used to store liquefied gases at temperatures down to – 200 °C and thermal conductivities of less than 0.003 W/mK are achieved. The challenge lay in carrying this insulation principle over to thermal energy storage at higher temperatures.

Vacuum minimises air heat transfer

The hot water storage tank consists of an inner and outer steel tank. Concentric cylindrical containers connected one below the other by a special fixture with low thermal bridging properties proved the most suitable. The aim was to reduce heat transfer within the annular cavity between the inner and outer tanks. Three mechanisms of heat transfer need to be reduced in this regard: Convection and thermal conduction through air molecules, thermal conduction along the solid powder body and thermal radiation. In order to inhibit air heat transfer, the researchers generated a moderate vacuum of 0.1 mbar between the inner and outer tank, achieved with simple pump technology. This is entirely sufficient as the perlite's micropores limit the mean free path of the air molecules.

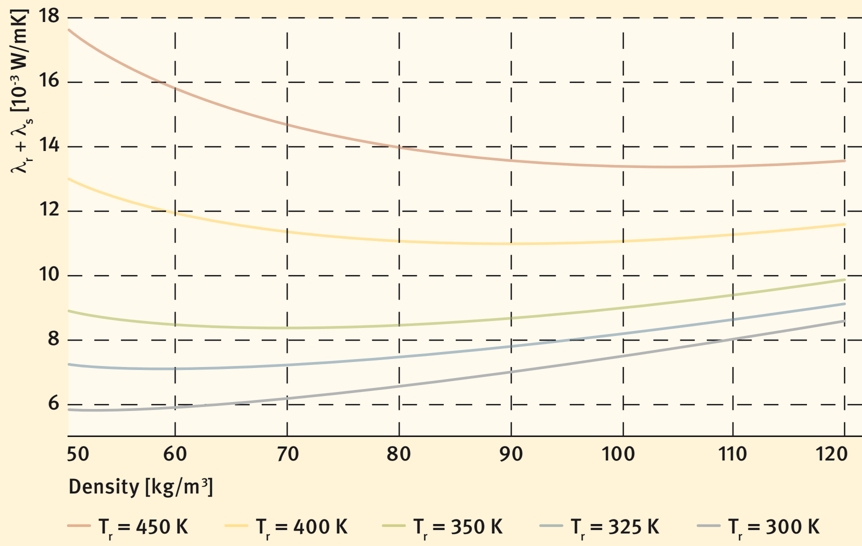

Fig. 1 *The thermal conductivity of the evacuated tank shell consists of radiation (λ_s) and solid-state thermal conductivity (λ_r) and is dependent on the density and average temperature (T_r) in the perlite filling.*

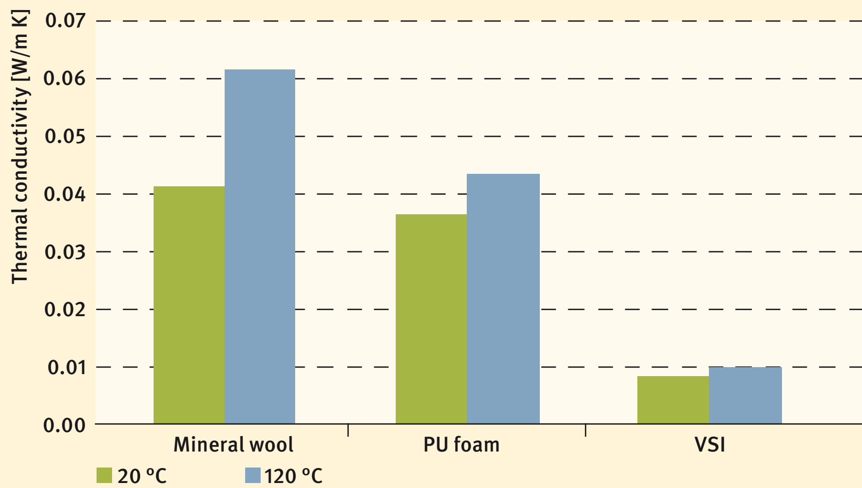

Fig. 2 *Comparison of thermal conductivity of conventional insulating systems with innovative VSI insulation at 20 °C and 120 °C average temperature.*

Perlite reduces thermal radiation

Unlike convection and thermal conduction, thermal radiation also occurs in the vacuum. All bodies radiate electromagnetic waves with a spectrum that is characteristic for their temperature and therefore exchange energy with their environment. In order to minimise this mechanism, perlite, which is a porous and consequently poorly thermally conducting volcanic rock, is poured into the annular cavity. The radiation is absorbed in the powder filling and re-emitted homogeneously in all directions. Diffusion also occurs at the powder grains. This drastically reduces the thermal radiation to the outer wall of the container.

The perlite-based vacuum super insulation delivers around five-times the level of insulation of dry conventional heat insulation at 100 °C when perfectly installed. The lowest level of thermal conductivity of the perlite achieved at storage temperatures of approx. 100 °C under laboratory conditions was around 0.008 W/mK. At a storage temperature of 200 °C, around 0.011 W/mK is achieved (Fig. 1). A 16.5-m³ prototype installed at company Hummelsberger achieved 0.009 W/mK at 90 K above ambient temperature in winter over a period of measurement of two months, corresponding to just 0.2 K of cooling per day. This value already includes connection losses. Thermal bridges on the VSI tank are the connection points for the solar and heating systems and the fixture for the inner tank inside the outer tank. As the wiring and storage tank fixtures are clad in evacuated perlite over large sections or are made from a poorly-conducting material, the proportion of the calculated total losses that these account for is just 0.3 %. A further reason for this low value is the large storage tank surface in comparison to the cross-sectional area of the conduit wiring.

Stratified charger with enhanced flap mechanism

In addition to the storage tank shell's insulation, thermal stratification within the storage tank affects its efficiency too. Mechanisms that inhibit the mixing of hot and cold water in the storage tank are ideal. The researchers developed a stratified charger with an optimised flap mechanism. Outlet ducts branch off from the main vertical conduit of the stratified charger. A reversal mechanism was attached at each of these outlets. A plastic disc lies flat on each outlet opening, providing a seal. The flaps are opened only by the upward force of the hot fluid. If colder fluid flows past the flaps, these remain closed. The streaming of hot fluid in a conventional stratified charger by contrast would lead to a „depression" in the stratified charger, which would result in colder fluid reaching the stratified charger via the charging conduits. This is prevented by the flap mechanism and no mixing of the temperature layers occurs in the storage tank.

For the flap mechanism itself, a plastic is used with a density close to that of water. If a heavier material were to be used for the flaps, the density difference wouldn't be sufficient to raise the flaps or allow for stratification. The plastic that the stratified charger is made from demonstrates low thermal conductivity. This works to further thwart the vertical destruction of layering in the storage tank. The existing „flap principle" was optimised in the research project and a patent registered for the improvements made.

Use in single-family homes

The VSI tank has already seen use in heat supply applications in existing and newly constructed buildings. One example is a single-family home in Bergen with 230 m² of living space. In this property, an eleven cubic metre

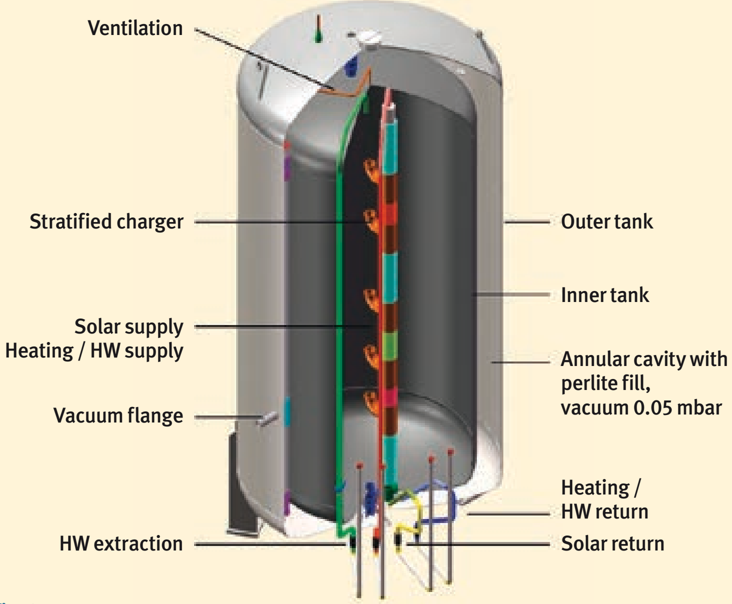

Fig. 3 *Schematic view of a VSI storage tank*

Fig. 4 *The VSI tank in Bergen is disguised by a storage facility for wood.*

Properties of perlite

Perlite is a naturally occurring mineral of volcanic origin. The hard base material obsidian ("volcanic glass") is transformed into "crude perlite" through ageing and moisture absorption. This material has a relatively high water content. The open-cast mined crude perlite exhibits a density of 900 to 1,000 kg per cubic metre and can be described as an almost inexhaustible raw material. For further use, the crude perlite is heated to between 850 and 1,000 °C. This causes the water held in the material to be vaporised and creates a microporous structure. The crude perlite is then cooled and its mechanical stability is consequently restored. Treated in this way, the "expanding perlite" has a much lower density of 30 to 240 kg/m^3 compared to the raw material. The low density and the high porosity make the expanding perlite a suitable material for vacuum super insulation. Further positive properties of perlite include the low price of around 50 euros per cubic metre and temperature resistance up to 800 °C. The material is also non-poisonous and incombustible. Perlite has a high porosity and therefore relatively favourable insulating properties including without evacuation. For this reason, alongside vacuum super insulation, the material is also used in large quantities as a loose fill insulating material in building construction and as a material for soil bulking in the agricultural sector.

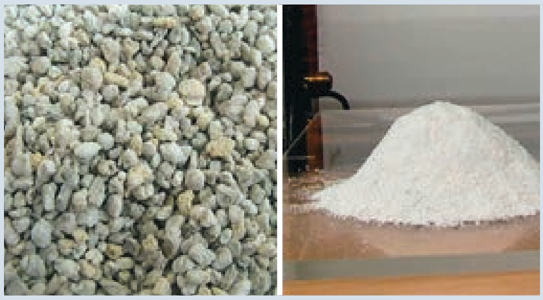

Fig. 5 *Rough grained crude perlite (left) and technically expanded perlite.*

storage tank was installed with half of the system below ground level. A mobile crane was used to lift the storage tank into the excavation. The hydraulic connection to the heating system was established in the boiler room. A solar energy system with a collector surface area of 55 m^2 feeds into the storage tank. The solar share of fraction is between 55 and 60 %. The remaining heat requirement is covered by a firewood plant and an oil-fired heating system.

Hummelsberger is currently constructing a VSI tank with a volumetric capacity of 37 cubic metres for a private building owner. The storage tank is being installed in a newly constructed building with 368 m^2 of living space and a total surface area of 600 m^2, which includes the basement, and will be adequate for the entire building structure from the basement to the roof. It was therefore particularly important to the building owner for the storage tank to be extremely well insulated with no thermal radiation into the building itself. Owing to the low thermal conductivity of its enclosure, this requirement is very well addressed by the VSI tank. A 97-m^2 solar energy system with evacuated tubes supplies heat to the storage tank. The remaining heat requirement is covered by a wood-fired heating system with water flow. This feeds heat initially to a small buffer storage tank via a heat exchanger. When this is filled, the heat is rerouted to the VSI tank. All instances of loading and extraction occur via this working storage tank in order to keep the movement of water as slight as possible in the long-term heat storage tank.

Huge potential for industrial process heat

To date, the VSI storage tank has predominantly been used for solar heat storage in residential buildings. Even greater potential, however, has been identified in the storage of industrial process heat. As the storage tank's losses are virtually zero, its benefits increase with the application temperature. It can be theoretically operated up to 750 °C as perlite is resistant up to this temperature. Modifications to the tank base material and the heat transfer medium, however, become necessary.

Integrating storage tank in existing rooms

Energy storage is a key issue of energy transition. In addition to the storage of electricity, the holding of thermal energy plays an essential role. Heat storage systems provide the core element for almost all larger-scale heat generation systems based on solar thermal energy, biomass and heat pump technology. They also play an important role with CHP plants. To ensure the ongoing wide-spread use of these technologies, existing storage technologies need to be adapted to current requirements.

As in the research project outlined, an essential objective in this regard is to increase the thermal storage capacity and storage duration while keeping temperature losses to an absolute minimum. Scrutiny of other research projects reveals practical considerations around, for instance, the optimal utilisation of existing options for storage tank installation, to play an important role alongside the pure efficiency of the storage systems.

In the now concluded “Innovative concept for cost-efficient ground buried hot water storage tanks” research project, researchers of the Institute for Solar Energy Research (ISFH) in Hameln developed a simple and building-independent storage system. The below-ground system has three to thirty cubic metres of volumetric capacity and is buried in the earth in immediate proximity to the building. The system consists of a concrete cistern, an XPS-based insulating material (extruded polystyrene hard foam) and a film lining for absorbing the storage tank water. The system constitutes a viable option for buildings without a basement or a suitable location for storage tank installation.

A rectangular storage tank constructed from fibreglass-reinforced plastic (GFRP) is currently in development. The aim of the project is to develop a storage tank that makes optimal use of available space and which can be carried into buildings via access routes with limited room to manoeuvre. The project involved the development of a storage tank consisting of individual modules intended for on-site assembly by the Ilmenau University of Technology and ed energie.depot GmbH in Radeberg.

Further research activities are being supported by the German government as part of the Energy Storage Funding Initiative. Recipients of funding include projects in the field of thermal storage exploring options for increasing storage density and cycle durability and reducing manufacturing costs. Alongside thermal storage, funding has also been concentrated around electrical and material storage systems. The German Federal Ministry of Education and Research and the German Federal Ministry for Economic Affairs and Energy made around 200 million euros of funding available for research projects in an initial phase up to 2014.

Project participants

- **Project management:** ZAE Bayern, Garching, Germany, Dr. Thomas Beikircher, thomas.beikircher@zae-bayern.de
- **Industrial partners:** Hummelsberger Schlosserei GmbH, Mühldorf am Inn, Germany, Jürgen Melzer

Links and literature

- www.vakuum-pufferspeicher.de
- www.forschung-energiespeicher.info

More from BINE Information Service

- Hauer, A.; Hiebler, S.; Reuß, M.: Wärmespeicher. Stuttgart: Fraunhofer IRB-Verl., 2013. 152 S., ISBN 978-3-8167-8366-4, 29,80 Euro (Print), 23,80 Euro (E-Book), BINE-Fachbuch
- Storing solar energy in the ground. BINE-Projektinfo brochure 01/2013
- This Projektinfo brochure is available as an online document at www.bine.info under Publications/Projektinfos.

BINE Information Service reports on energy research projects in its brochure series and newsletter.
You can subscribe to these free of charge at www.bine.info/abo

Imprint

Project organisation
Federal Ministry for Economic Affairs and Energy (BMWi)
11019 Berlin
Germany

Project Management Jülich
Forschungszentrum Jülich GmbH
Dr Peter Donat
52425 Jülich
Germany

Project number
0325964A

ISSN
0937 - 8367

Publisher
FIZ Karlsruhe · Leibniz Institute for Information Infrastructure GmbH
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Author
Birgit Schneider

Contact · Info

Questions regarding this Projektinfo brochure? We will be pleased to help you:

+49 228 92379-44
kontakt@bine.info

BINE Information Service
Energy research for application
A service from FIZ Karlsruhe

Kaiserstraße 185-197
53113 Bonn, Germany
www.bine.info

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Concept and design: iserundschmidt GmbH, Bonn – Berlin, Germany · Layout: KERSTIN CONRADI · Mediengestaltung, Berlin, Germany