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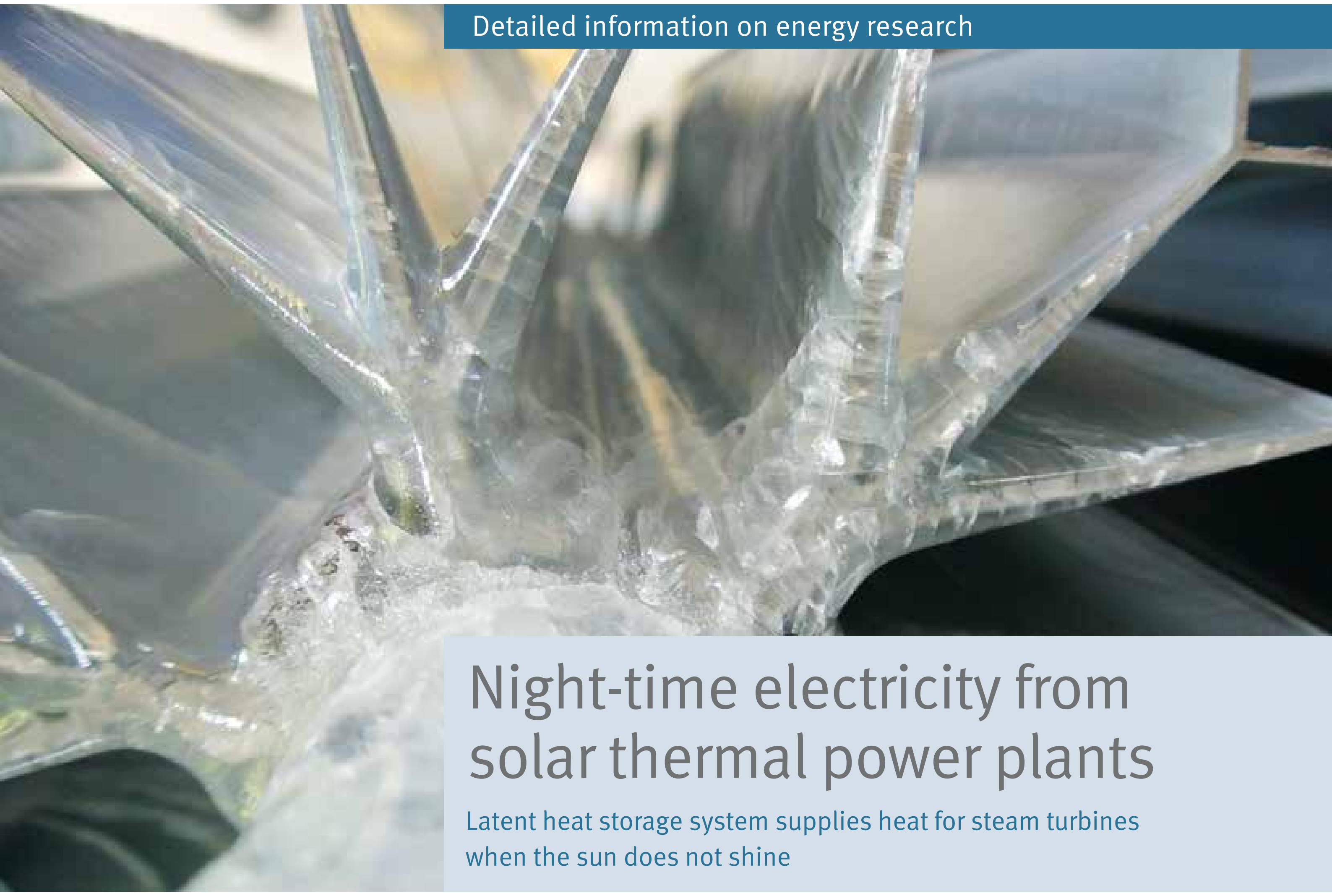
Detailed information on energy research



Night-time electricity from solar thermal power plants

Latent heat storage system supplies heat for steam turbines when the sun does not shine

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Together with the industrial partner Linde AG, researchers from the German Aerospace Center have further developed a latent heat storage system based on nitrate salts. In combination with a cascade of sensible heat storage units, the goal is to maintain the electricity production of solar thermal power plants at night and at times with low solar irradiation. To this end, the scientists have developed a storage system that can also be used for conventional steam power plants and industrial processes.

Using heat storage systems, solar thermal power plants can supply electricity around the clock – almost like conventional power plants. Their output can be more easily planned and they can provide balancing capacity for the power grid. The optimised heat management also improves the operating behaviour, reduces the partial load operation and uses the power block more efficiently. The overall economic efficiency therefore also increases.

Solar thermal power plants operate particularly efficiently and cost-effectively when they are operated at high temperatures. This is possible with the direct solar evaporation of water, whereby the superheated steam for the steam turbines is generated in the collector. It reaches temperatures of over 500 °C at a pressure of 120 bar. These steam parameters are almost equivalent to those common in conventional power plants.

“Direct steam generation in solar thermal power plants enables higher efficiency levels. However, coupling with a thermal energy storage system would make the most sense for evening operation. For this purpose, a storage system needs to be developed and optimised,” explains Maike Johnson, manager of the DSG-Store project. DSG-Store stands for “Direct Steam Generation Storage”. The direct steam generation and superheating of the feed water in the heliostat field is already

commercially available in parabolic trough, Fresnel and tower power plants. The disadvantage until now, however, has been the lack of thermal energy storage systems. To enable these to be used reliably for direct steam generation, various components need to be further developed, the system structure optimised and operating concepts tested. Within the research project, the German Aerospace Center (DLR) has developed a new generation of thermal energy storage systems in conjunction with Linde AG.
The system developed by the researchers consists of a cascade comprising a latent heat storage unit for the condensation and evaporation and three sensible liquid salt storage tanks for the superheating of the steam. The researchers consider this to be the most promising solution in technical and economic terms. The entire system is designed for use in all solar thermal power plants with direct steam generation, irrespective of the concentrator system used, and therefore suitable for parabolic troughs, linear Fresnel collectors and tower receivers. In addition, the system can be used in both industrial steam processes and conventional steam power plants.

Storage cascade for different temperatures

To ensure that as much heat energy from the collector is stored as possible, the scientists have developed the concept of a multi-stage storage cascade. This consists of "hot" (527 °C), "warm" (400 °C) and "cold" (306 °C) sensible heat storage units followed by a single latent heat storage unit. These first three storage units absorb the thermal energy in molten salts as sensible heat, i.e. through temperature increases. The molten salt is located in insulated steel tanks whose components and materials are adapted to the temperature level and corrosiveness of the salts. The latent heat storage tank is used as the fourth and last storage unit.
If the solar thermal system provides more steam than the power plant requires, the storage tanks can be charged: the superheated steam enters the first heat exchanger at 550 °C. There, it heats liquid salt that is pumped out of the warm storage tank and is then directed into the hot storage tank. In the same way, the now colder steam in the second heat exchanger brings the molten salt from the cold storage tank to the temperature level of the warm storage tank. Following this step, the steam is cooled down to such an extent that only the condensation energy can be decoupled. Since the condensation takes place at a constant temperature, a sensible heat storage system would only be able to absorb the energy with temperature and therefore exergy losses. This is why the scientists are using a latent heat storage unit optimised for this purpose. It works with salts whose melting temperature corresponds to the temperature of the condensation process.
At night and when the sky is overcast, the storage units supply the energy for the steam power plant. In order to generate the steam for the turbines, these are discharged in reverse order. Initially, the latent heat storage unit heats and evaporates the feedwater. The two heat exchangers then heat the steam further using energy from the warm and hot tanks. The molten salts cool down during this process and are pumped into the respectively next colder tank.

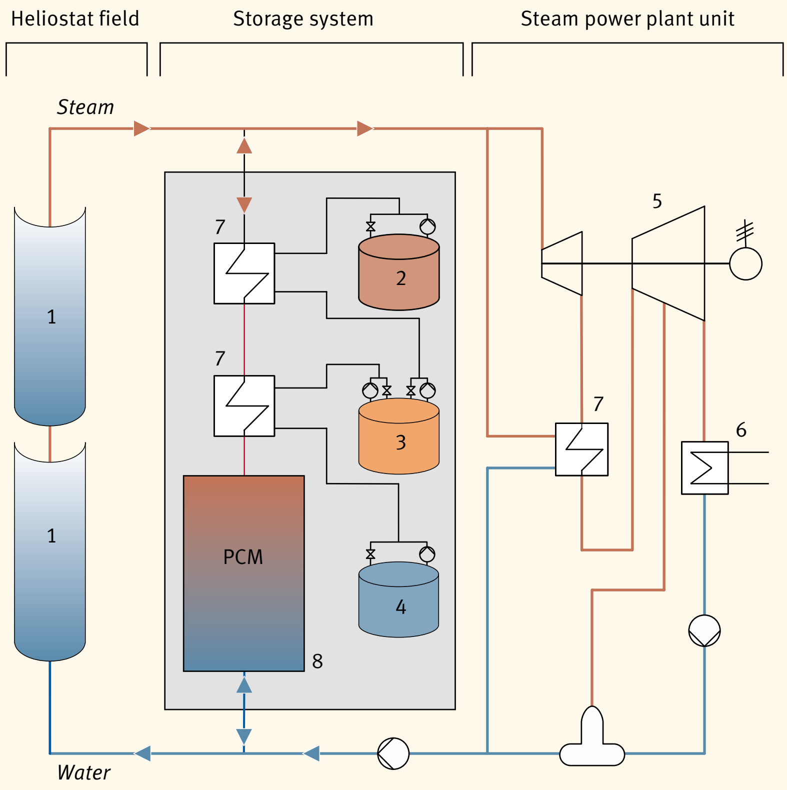

Fig. 1 *Integration of the storage cascade system into a parabolic trough power plant with direct steam generation.*

Formed like a snow crystal

Although the superheated steam reaches 550 °C, about 65 % of the solar energy is used solely for the evaporation process. The latent heat storage unit, which absorbs this energy portion, is therefore accordingly important. The storage medium used is sodium nitrate. This melts at 306 °C, which needs to be paired with a cooler condensation temperature and somewhat warmer evaporation temperature for the discharging and charging of the storage. The temperature difference between the melting temperature and the condensation or evaporation temperatures is typically about 10 degrees Kelvin. The sodium nitrate is located in a thermally insulated container in direct contact with the heat exchanger tubes, through which the steam flows during charging. During this process, the steam cools and condenses. The latently stored energy is released and the salt melts with a phase change enthalpy of 175 kJ/kg. For discharging, feedwater flows through the storage unit tubes. The liquid salt solidifies and transfers the crystallisation energy to the water.
As simple as the storage principle is, several details are difficult to implement in practice. For example, the salt changes its volume during the phase change, which needs to be taken account of in the design. At the same time, however, the materials and production costs need to be kept low. A particular problem of this type of storage results from the low thermal conductivity of the salts used. If the storage tank is discharged, the salt first

Fig. 2 *The figure shows the investigated latent heat storage tank on a pilot scale.*

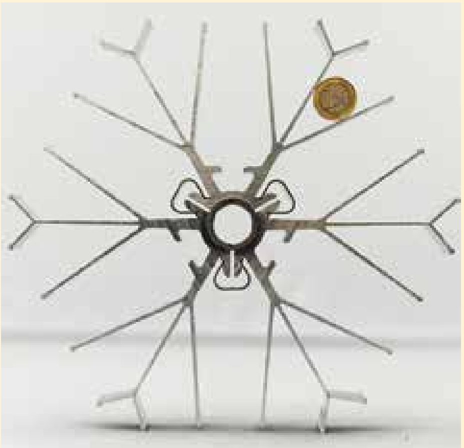

Fig. 3 *Through the axially finned tube, steam flows through the latent heat storage tank at high pressure. The heat is transferred to the salt via the fin structure.*

Direct steam generation instead of thermal oil

Most solar thermal power plants operate with thermal oil that transports the heat from the parabolic trough collectors to the power plant and produces steam there. The heat transfer fluid limits the operating temperature, since it decomposes above about 400 °C. Heat storage systems have been integrated into some power plants of this type. For example, the Andasol power plants in the Spanish province of Granada have storage tanks with molten salt. These store thermal energy to enable the power plant turbines to operate for 8 hours under the full load of 50 MW_{el}.

Thanks to the higher temperatures, direct steam generation achieves significantly higher efficiencies. With the same mirror surface, considerably more electricity can therefore be generated and, with heat storage systems they can achieve greater capacities. The system configuration also becomes simpler: whereas the thermal oil first generates the steam in the power plant via a heat exchanger, the directly generated steam is directly coupled into the steam turbines in the power plant.

"Molten salt" power plants also achieve high temperatures. They use molten salt that can be heated to 565 °C as the heat transfer fluid. However, the melt can solidify if its temperature drops below about 240 °C. It can then only be re-liquefied with considerable effort. For this reason, the thin receiver tubes are either heated at night with considerable energy expenditure or – according to a new concept – emptied, whereby the heat carrier is temporarily stored in well insulated containers.

solidifies where the heat is extracted, i.e. on the heat extractor surface. An increasingly thicker salt crust forms that increasingly impedes the heat flow as an insulating layer. Here, help is provided by creating the greatest possible surface area for the heat exchanger using extended fins. These should have a good and reliable thermal connection to the heat exchanger tube, cover as much of the area of the storage tank as possible while simultaneously minimising the introduced fin volume.

The scientists optimised both the geometrical structure and the individual components with a test storage tank at a pilot scale. They were able to build on the findings from the previous DISTOR and ITES projects as well as the parallel TESIN project. In addition to the technical performance of the storage module, the researchers were also concerned with the economic aspects.

In some of the previously tested PCM modules, annular fins ensured the heat flow between the heat transfer tubes and the salt. The researchers came to the conclusion that axial fins made of extruded aluminum could be produced more cheaply.

In the course of the work, the scientists investigated more than 20 different axial fin profiles, which were optimised in varying geometrical forms considering both technical and economic aspects. The best of these simulated profiles was tested in the laboratory for its suitability in practice. Simulation models and experiments have resulted in a six-armed aluminum profile that resembles a snow crystal. The structure is composed of three parts, which are fastened to the transfer tube by clips. This clipping technique has proven to be the best method for affixing the fins to the tubes in the experiments. The close correlation between the experimental results and the calculations also shows that the simulation model can accurately depict the new structure's heat transfer.

Testing in practice and optimisation

"We want to optimise the storage tanks to achieve a more constant discharge capacity and to minimise the temperature difference between charging and discharging. This would enable the steam turbine to achieve a greater output in storage operation and the inefficient sliding pressure operation would be minimised," says Maike Johnson in explaining the further research goals. The scientists at DLR see the technological potential provided by active latent heat storage concepts. Thus far there have only been a few studies in this area, so that the possibilities are not sufficiently clarified and exhausted. Thermal energy storage concepts can contribute to more flexible electricity networks and compensate for fluctuating electricity generation from renewable energy sources. "An interesting area of research is, for example, the conversion of excess electricity into heat and its reconversion as required," explains the researcher.

Salt as a heat carrier and storage medium

High temperatures and good efficiency are also achieved by the “molten salt” technology, which uses molten salts for the heat transport. Within the High Performance Solar (HPS 2) project, scientists at DLR are leading research into the economic viability and operational safety of parabolic trough plants with liquid salt.

In an innovative continuous-flow steam generator, the salt transfers its energy to a connected water-steam circuit. The increased steam pressure and temperature parameters enable both greater efficiencies in the power plant block and supercritical steam conditions for commercial applications. The components and the entire system belonging to the test facility in Évora in Portugal are being adapted for use of molten salt as the heat transfer medium for the operation. The project is being funded by the German Federal Ministry for Economic Affairs and Energy.

Making steam and waste heat usable

Researchers from the Fraunhofer Institute for Solar Energy Systems ISE have developed a salt-based latent heat storage system that operates with one tank for the molten and one for the solid granulate salt. A new type of screw heat exchanger decouples the storage capacity from the installed heat exchanger surface. The system has been integrated and tested in the PE1 Fresnel power plant in southern Spain. The aim of the German Federal Ministry for Economic Affairs and Energy project entitled “Salt-based latent heat storage for solar steam generation and waste heat utilisation” – or SALSA for short – is to develop a functional storage system for direct steam generating solar thermal power plants and industrial processes.

Latent heat storage for industry

In the TESIN project, scientists at DLR are investigating the possibilities for applying high-temperature latent heat storage systems. These are intended to increase the energy efficiency of industrial processes, power plants and the heat supply. In a first step, the possible technical and economic potential provided by integrating storage systems in steel mills and combined heat and power stations was determined. A storage unit further developed for this purpose for high power densities and superheating replaces the boiler provided for standby back-up purposes. To this end, it needs to be able to produce the superheated steam for at least 15 minutes. Previous latent heat storage units have only been designed for saturated steam and are not configured for longer discharge times or lower outputs.

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Links and literature (in German)

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