New Solar Thermal Storage Concept
– Combined Hot Water and Sorption Store –

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Abstract

A new concept for solar thermal energy storage combining a conventional hot water store with a sorption store is being developed and investigated at the Institute of Thermodynamics and Thermal Engineering (ITW), University of Stuttgart. The particular advantages of the two storage technologies – sensible heat and sorption – complement one another optimally. The hot water store is used as short-term store providing a high heat supply rate. The sorption store enables long-term storage almost without any losses. For this application long-term means several days or weeks. The combined hot water and sorption store intends to improve the performance and efficiency of a solar thermal system for domestic hot water preparation (DHW) and ensure heat supply entirely on a solar basis during the summer period. The fundamental adsorption and desorption behaviour has been determined by experiments on a sorption store in laboratory scale with a volume of about 4 litre. A full-scale prototype store, consisting of a sorption store with a volume of 100 litre inside a DHW store, is being constructed and will be monitored in laboratory.

1. Introduction

Energy storage is required to achieve a continuous supply of heat by solar thermal systems for domestic hot water, as solar radiation is subject to daily variations and fluctuations. To increase the solar fraction and the performance of solar thermal systems a new approach for the storage of solar thermal heat is pursued at the Institute of Thermodynamics and Thermal Engineering (ITW), University of Stuttgart, combining a common domestic hot water store with a sorption store.

In this concept the hot water store, as the conventional part, is used for short-term storage providing a high heat supply rate. The sorption store offers the advantage of long-term heat storage almost without losses. In times of high solar radiation, surplus heat can be stored. This heat can be released during low-radiation periods, where heat supply of the solar thermal system is not sufficient. In the context of this application long-term storage is not meant as seasonal but rather to bridge few days or weeks. Longer periods of adverse weather occur even during summer months and hence the available solar radiation for domestic hot water preparation is not sufficient after a couple of days as the only energy source, since a common solar hot water store for detached houses (approximately 300 litre) only allows a short-term storage for several days due to limited thermal capacity and energy losses.

The concept of the combined store ensures heat supply during summer completely on a solar basis. Furthermore an improved performance of the system results from the combination of a hot water and sorption store compared to a common solar thermal system solely containing a hot water store.

2. Sorption Store

Energy storage through sorption processes is based on the use of the adsorption enthalpy that is released when an adsorbate is adsorbed on an adsorbent, for example water vapour on zeolite. In an open sorption process humid air can be blown through the sorption material for instance. To regenerate the sorption material heat on high temperature level has to be delivered. With this technology the inserted energy can be stored for an arbitrary time.

Basic considerations and examinations on the combined hot water sorption store are carried out using the sorption material zeolite 4A. The properties of zeolite 4A are well-known. The material is manufactured commercially, is cost-efficient, robust and shows good adsorption properties.

In general the concept is not restricted to one single material. In the near future new materials are to be expected [1] and can be used as long as they have a high loading capacity at low partial pressures and a relatively low temperature level for desorption.

3. Combined Hot Water and Sorption Store

Previous research projects about sorption storage focused on space heating only [2], [3]. A direct coupling of a sorption store with a hot water store is investigated for the first time in this project.

In terms of its basic construction the presented system matches a typical solar thermal system for domestic hot water preparation as it is commonly used for detached houses in Germany. But as an essential difference the typical hot water store is replaced by a combined hot water and sorption store.

There are several advantages of this concept: On the one hand the connection to an existing heating installation can be maintained without modification. This results in simplified system integration. Furthermore the advantages of both of the two storage principles (sensible heat and sorption) can be combined in an ideal way. The hot water store offers a high heat transfer capacity and the sorption store heat storage of “surplus” heat almost without any thermal losses.

Stagnation in solar thermal systems usually occurs when irradiation exceeds the demand of heat and the hot water store is charged completely. In contrast to common systems where the “surplus” heat available during stagnation periods is not used, the system with a combined hot water sorption store uses the “surplus” heat to recover the sorption material. The sorption material remains in that state as long as it does not come into contact with water vapour. In times when the energy stored in the hot water tank cannot satisfy the demand of heat anymore, humid air is fed to the sorption material and the released heat is delivered to the hot water store. Thus a general disadvantage of solid materials stores, the relative low heat supply rate, becomes insignificant. The sorption store can release energy with low power over longer time to the hot water store that acts as a buffer store.

To obtain a loss-free storage, it is implied that losses from the sorption store are recovered within the system. Losses from the sorption store primarily occur during the desorption process. With regard to this aspect an integration of the sorption store into the hot water store was identified as an efficient way, also keeping in mind a simple construction. In this concept the sorptive energy storage process can be realized as an open or a closed adsorption process in principle.

In a **closed** system adsorption is initiated by water vapour generated by evaporation of liquid water. Therefore an evaporator and condenser including a water tank are required to be part of the storage system. To facilitate evaporation in a temperature range of 20°C to 30°C degrees the process has to be performed at low pressure (20mbar). The energy needed for evaporation can be delivered by the solar collector, if an appropriate irradiation is available.

The **open** process is performed at ambient pressure. Water vapour for adsorption is provided by the humidity available in the ambient air. The air is blown through the sorption material by a fan. The pressure drop can be reduced e.g. by minimizing the way of the flow. This can be realized by a radial flow instead of an axial flow. With regard to a simple construction and cost-efficient production the open process offers clear advantages.

The adsorption and desorption process in an open sorption store are presented in figures 1 and 2. For discharge (adsorption) humid ambient air is blown through the coaxial pipe and passes through the packed bed of zeolite spheres. The radial concept reduces the pressure drop. Water vapour is adsorbed on the zeolite and adsorption enthalpy is released. The hot air enters the annular gap between the sorption material and the wall of the sorption store and flows along the wall, releasing heat to the surrounding water of the water store. The cooled air escapes through the pipe in the centre.

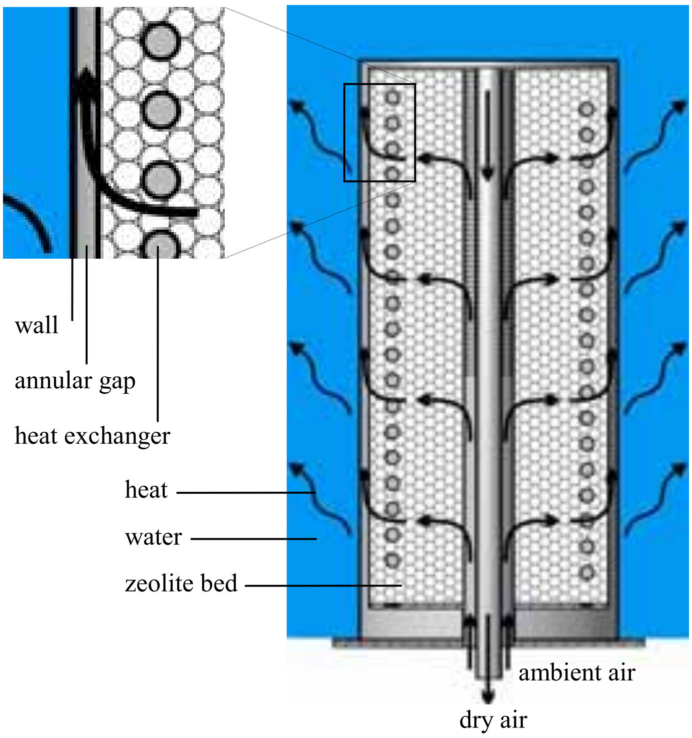

Fig. 1. Adsorption

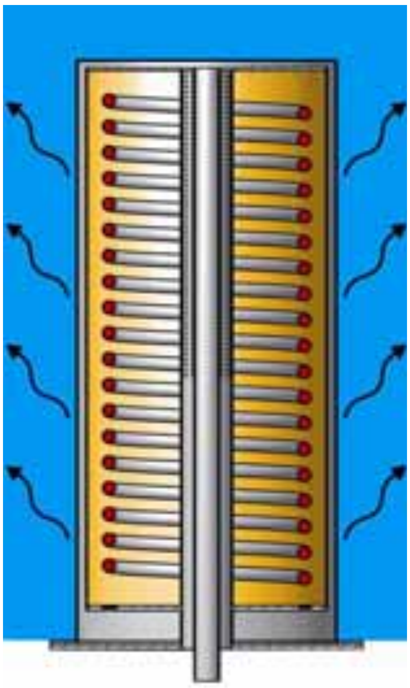

Fig. 2. Desorption (zeolite bed not displayed to highlight the heat exchanger)

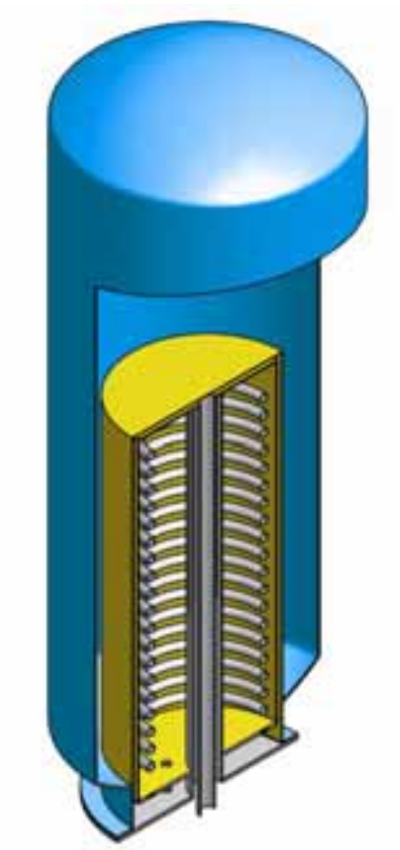

Fig. 3. Cross section of the combined hot water store (outside) and sorption store (inside)

To charge the sorption store (desorption), as shown in figure 2, a heat exchanger is included in the fixed bed of zeolite and the solar collector provides the energy to heat the sorption material. A previous project about a sorption store demonstrated, that zeolite can successfully be desorbed by CPC-collectors [2] as temperature levels up to 180°C can be achieved with a reasonable collector efficiency of 35%. Desorbed water vapour reaches the outer wall of the sorption store and condenses, releasing condensation enthalpy. “Energy losses” during the charging process are transferred to the hot water store and therefore maintained within the storage system. Desorption is started, when the hot water store is almost charged and solar radiation is still available.

The concept shall be realised and tested by a prototype store. A prototype is currently being constructed. The sorption store will be included into a DHW-store as an entire unit of 100 litre by a flange from the bottom side. The specific storage capacity of the sorption store is expected to be around 120 kWh/m^3 resulting in a capacity of 12 kWh with regard to the prototype. This is sufficient to heat about 300 litre of water. A sketch of the planned hot water store including a sorption store is shown in figure 3. The prototype will be monitored in laboratory under defined boundary conditions.

4. Experimental Investigations

In a first step experimental investigations were conducted on a sorption store (radial flow adsorber) in laboratory scale with a volume of about 4 litre. The experimental setup is presented in figure 4. In figure 5 a view from the top into the sorption store is shown. The influence of important parameters, such as temperature, air humidity, inlet velocity and heat transfer to the ambient on the adsorption behaviour were determined. Temperature curves as well as the humidity over time of an exemplary experiment are presented in figure 7. The positions of the thermocouples are indicated in the sketch on the left. An adsorption front moves through the packed bed. An analysis of the experimental data showed, that the material almost reached the maximum loading of 18% by weight. Temperature in the outer area of the sorption material (T_4) constantly raised about 30 K in this experiment.

The experimental setup for experiments with the same 4 litre sorption store but included in a water store is shown in figure 6. For these experiments heat for desorption was brought into the sorption material by a spiralled electric heating. Temperatures were measured in four radial positions in the

Fig. 4. Experimental setup for adsorption and desorption experiments (sorption store opened)

Fig. 5. View from top into radial flow adsorber filled with zeolite (top cover removed)

Fig. 6. Experimental setup for desorption experiments, sorption store from Fig. 4 and 5 including electric heating integrated into water store

zeolite bed. Water temperatures in the range from 25°C to 60°C were investigated in the experiments. The experiments showed that the sorption material could be heated up, despite that the sorption store was integrated in the water tank and hence surrounded by water, while the outer wall of the sorption store remained cool. The temperature of the outer wall did, during a desorption time period up to 12 h, not rise by more than 3 K compared to the water temperature in any experiment. A steep temperature gradient could be noticed in the area close to the outer wall and especially in the air gap next to the wall. The desorbed water vapour condensed at the outer wall and hence condensation enthalpy can be recovered.

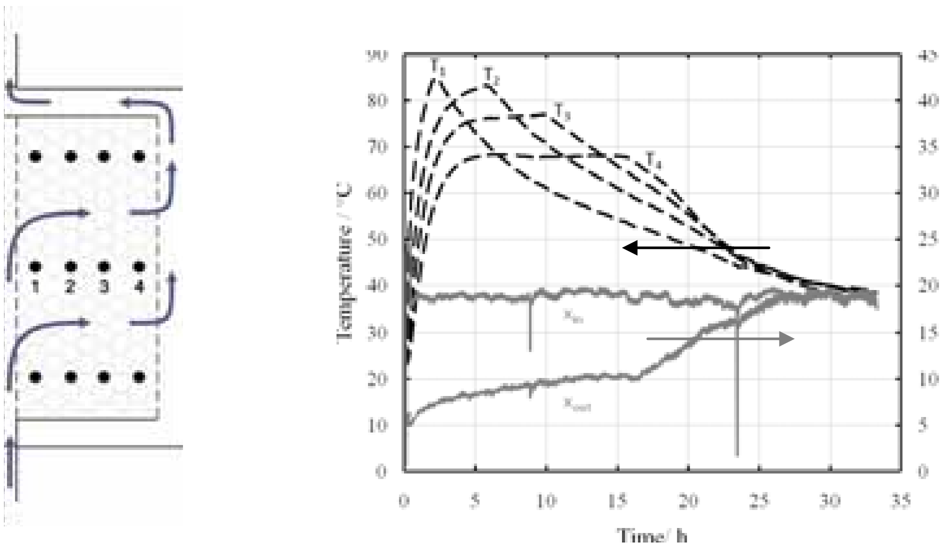

Fig. 7. Position of thermocouples in sorption store (left), measured temperature and humidity over time (right)

5. Numerical Investigations

TRNSYS-Simulation studies with a simplified model already show the potential of the combined hot water and sorption store. The energy saving per year for a solar domestic hot water system operated in combination with a hot water sorption store with an entire volume of 300 litre including a sorption store of 120 litre is around 20% higher compared to a conventional water based system if a daily use of 200 litre water at 45°C is being taken as a basis. The simulations were carried out with the reference weather data of Wuerzburg, Germany. It was observed that the number of days where auxiliary heating was needed could be drastically reduced.

Computational fluid dynamic tools (CFD) are used to simulate the flow and thermal conditions in the sorption store as well as the interaction with the surrounding water and serve as an instrument for the dimensioning and optimization of the prototype store. An adsorption model [4] was implemented into the simulation software. The model is being verified on the basis of laboratory experiments.

6. Conclusion

In the present article a concept for the realisation of a combined hot water and sorption store is presented for the first time. The hot water store offers a short-term storage providing a high heat supply rate. The sorption store enables an almost loss free storage of “surplus” energy from periods with high solar radiation.

The sorption store is constructed as radial flow adsorber. An open adsorption process was identified as more feasible compared to a closed process. “Energy losses” of the sorption store that arise during desorption are used by the system due to the direct integration of the sorption store into the hot water store.

The developed combination of a hot water store and a sorption store enables high solar fractions even in longer periods of adverse weather during summer months while the auxiliary heating is off and therefore increases the performance of the whole solar thermal system.

Based on the theoretical considerations as well as on the experimental and numerical investigations a prototype store is under construction. The prototype shall be investigated in detail under conditions close to reality.

Acknowledgement

The research and development project “KoWaSS“ is funded by the Department of the Environment Baden-Wuerttemberg within the Framework Concept “Baden-Württemberg Research Program Securing a Sustainable Living Environment (BWPLUS)“ (fund number BWK27008) and managed by the Project Management Agency Research Centre Karlsruhe (PTKA).

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