# THERMO-CHEMICAL STORAGE FOR SOLAR SPACE HEATING IN A SINGLE-FAMILY HOUSE

D. Jaehnig, R. Hausner, W. Wagner, C. Isaksson

AEE – Institute for Sustainable Technologies
Feldgasse 19, 8200 Gleisdorf, Austria
Tel: +43-3112-5886-28
d.jaehnig@aee.at

## 1. BACKGROUND

The development of an efficient and cost-effective heat storage is still one of the major technical challenges for the widespread use of solar thermal energy for space heating.

Up to now solar heat has been stored mostly in well insulated water tanks. The volume of these tanks is as large as 3 m³ for relatively high solar fractions and up to 70 m³ for full solar coverage for a single-family house. Storage tanks of this size are expensive and space consuming. In new buildings, provisions can be made to accommodate large storage volumes but this type of system is not likely to become a standard heating system. For retrofitting, large storage volumes are often impossible because of its space requirements or simply the fact that large tanks cannot be brought into the building.

Sorption heat stores are a promising approach to reach high solar fractions with relatively small storage volumes. A number of theoretical studies as well as laboratory tests have been performed in recent years (Welteroth and Mittelbach (2001), Núñez et al. (2003), Gartler et al. (2004)). The general functioning of the principle has been shown. The goal of the project described in this paper was to improve the system design in order to reduce system losses and to improve the overall performance of the system.

A new prototype system has been designed and tested in the laboratory. A number of different materials have been suggested for use as adsorbent and working fluid (Núñez (2001)). In the underlying project, silica gel and water have been used as working pair. The reasons for choosing this material are that silica gel and water are environmentally harmless, relatively cheap (mass production) and that the temperature needed for almost complete desorption can easily be reached with standard flat plate collectors.

## 2. PRINCIPLE OF A CLOSED-CYCLE SORPTION HEAT STORE

A sorption heat store is in fact a thermo-chemical heat pump which is operated under vacuum conditions. This allows evaporation at a low temperature level and water vapor transport without the need of a pump or fan. The basic principle is described below and shown in figure 1:

1. **Charging process (desorption, drying of adsorbent):** Heat from a high temperature source (solar thermal collectors) is fed into the device, heats the adsorbent and vapor is desorbed from the adsorbent. The desorbed vapor is condensed at a lower temperature level and then pumped out of the container into a separate reservoir. The heat of condensation has to be withdrawn to the environment.

2. **Storage period:** The dry adsorbent is separated from the liquid working fluid (the connecting valve is closed). As long as these components stay separate, long-term heat storage without losses is possible if the sensible heat involved is neglected.

3. **Discharging process (adsorption of working fluid on adsorbent):** Water is pumped into the evaporator where it evaporates taking up heat at a low temperature level. The vapor is adsorbed and releases the adsorption heat at a higher temperature level. This is the useful heat that can be used for space heating.

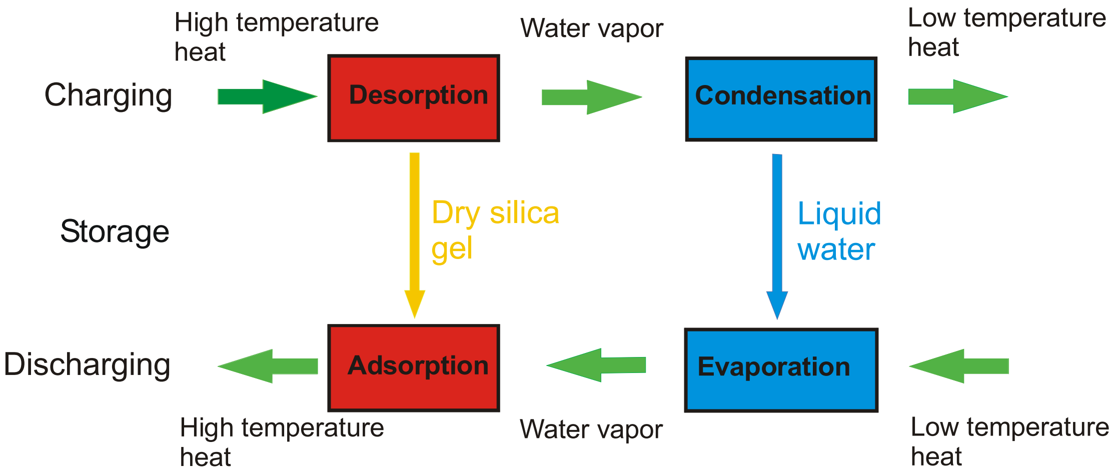


**Figure 1: Working principle of a closed-cycle adsorption heat store**

## 3. SYSTEM DESIGN

Within the framework of the EU-project MODESTORE, a prototype storage module has been developed (figure 2). The upper part contains the adsorber and a spiral heat exchanger. In the center, there is a vertical channel for vapor diffusion. The spiral heat exchanger consists of perforated sheet copper with copper pipes soldered to it. The lower part contains the heat exchanger that serves as evaporator and condenser. At the bottom, the container is connected to a second container that holds the water that is not adsorbed. For desorption the water is pumped from the storage module as it accumulates at the bottom. For adsorption, water is led into the bottom of the storage container and heated.

The advantage of the new design is that it is very compact. All major components (adsorber and evaporator/condenser heat exchanger) are included in a single container. The distances between adsorber and evaporator/condenser are very short. The vapor does not have to pass through narrow pipes which reduces the pressure losses.

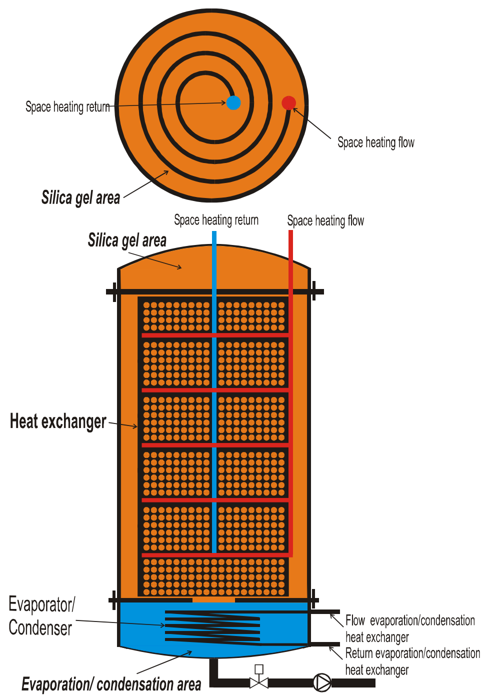


**Figure 2: Prototype storage module**

In addition, in previous prototype systems (Welteroth and Mittelbach (2001)) the evaporator was submerged at the bottom of a large tank containing the entire water for adsorption. This led to poor heat transfer from the evaporator to the water surface where evaporation takes place. In the new design only a small amount of water for evaporation is pumped into the evaporator area at the bottom of the tank module. This improved the heat transfer significantly.

The tested prototype store contained approximately 200 kg of silica gel.

## 3. EXPERIMENTAL SETUP

A number of adsorption and desorption tests under different operating conditions have been performed. A test rig including a heat source and a heat sink was constructed that allowed to supply the desired inlet temperatures and flow rates to the heat exchangers for the different test runs. The experimental setup is shown in Figure 3.

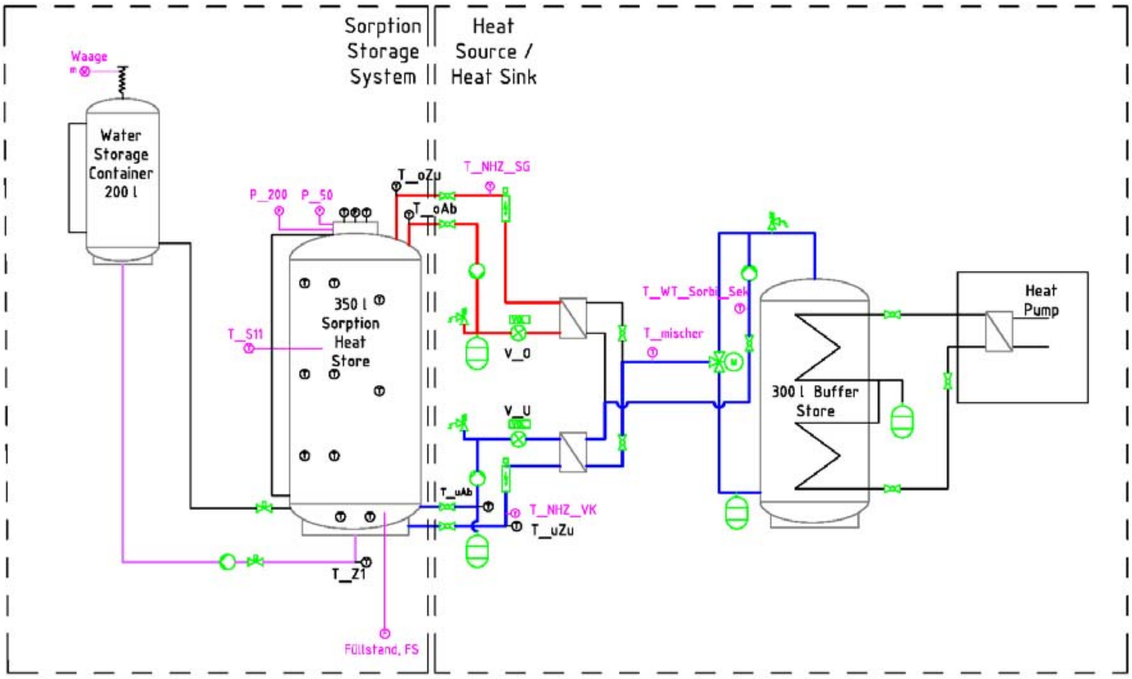


**Figure 3: Setup of the test facility**

On the left hand side, there is the sorption storage system with the main heat store containing the adsorber and the evaporator/condenser heat exchanger. In the upper left hand corner, the water storage container is shown. The heat exchanger in the adsorber part of the store is connected to an external heat exchanger. For desorption test runs, this upper circuit is used as a heat source using an electrical heating element to control the inlet temperature to the adsorber heat exchanger. The evaporator/condenser heat exchanger is also connected to a heat exchanger. This circuit contains also an electrical heating element that can be used as heat source for evaporation in adsorption mode.

The buffer store and heat pump on the right hand side are used as a heat sink and can be connected to the upper circuit for adsorption runs. In this case, the heat sink simulates the space heating load of a building. For desorption runs, the lower circuit is connected to the heat sink for condensation purposes.

The inlet temperatures and flow rates to the adsorber heat exchanger as well as the evaporator/condenser heat exchanger can be chosen freely between 10°C (limit of the heat pump) and 90°C (limit of the components in the hydraulic circuits).

## 4. DESORPTION

During desorption the most critical parameter is the temperature level that is available as a heat sink for condensation. Figure 4 shows a comparison of two desorption test runs. The starting point of the comparison is chosen so that both start at a water content of 9.8%. The water content is stated as kg of adsorbed water per kg of dry silica gel (%). The same inlet temperature to the adsorber heat exchanger has been used in both cases (88°C). The test run with 15°C inlet temperature to the condenser is indicated with thin lines, the test with 38°C with bold lines. Because the test run with 38°C condenser temperature was started at a much higher water content, the section shown here starts already at higher adsorber temperatures.

Figure 4 shows that the water content decreases significantly faster with lower condensation temperatures and also reaches a lower minimum. Interestingly enough becomes the slope of the curve very small approximately at the same time in both cases (after about 12 hours of operation). Although the temperature conditions were not equal for both experiments, the final adsorber and condenser temperatures were the same and the experiment was continued for several hours to be sure that a stable water content was reached.

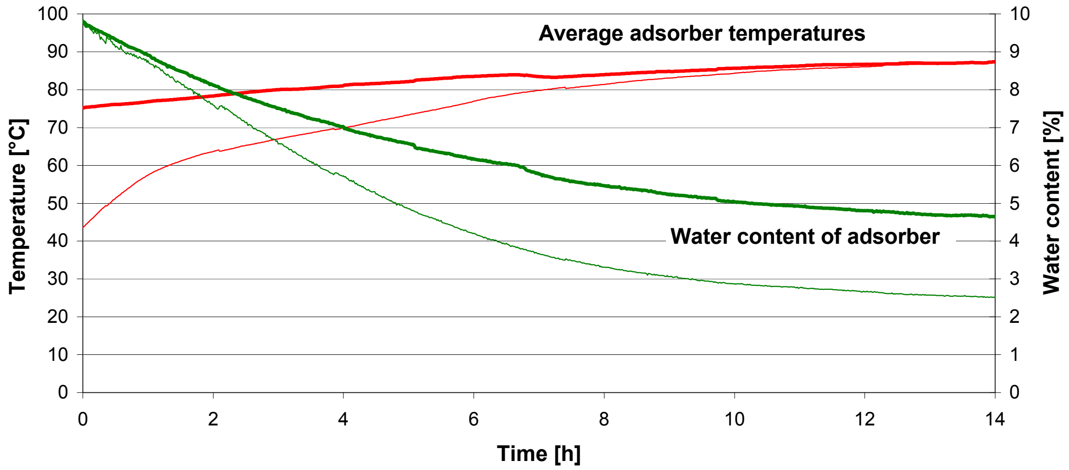


**Figure 4: Desorption with two different condensation temperatures**

A comparison between the theoretical minimum water contents under the operating conditions of the two test runs described above shows that the theoretical values have almost been reached (see Table 1). The measured values were reached after 2-3 hours of steady state operation (the water content reached a constant value). When comparing these figures one has to bear in mind that in a real application there is a pressure drop between the silica gel and the condenser although this pressure drop is very small in the newly developed system design. Secondly, there is a temperature loss across the condenser heat exchanger that causes the actual condensation temperatures to be a little higher than the inlet temperatures on the fluid-side of the heat exchanger.

**Table 1: Comparison between desorption with different condensing temperatures**

| Condenser inlet temp. | ΔT = Adsorber temp.- Condenser inlet temp. | $x_{theoretical}$ | $x_{measured}$ |
|---|---|---|---|
| [°C] | [K] | [%] | [%] |
| 15 | 72 | 1.85 | 2.04 |
| 38 | 51 | 3.85 | 4.13 |

The results show that even with condensing temperatures as high as 38°C very low water contents can be reached. That means that it is possible to use the return temperature of the space heating loop as heat sink. This may be an interesting operating mode during cold but sunny days in winter.

Moreover, an interesting option is to use the solar thermal collectors as a heat sink for condensation during night time. During the day, the adsorber is heated with the solar thermal collectors but no desorption takes place. During night time, when the collector temperature has fallen well below the necessary condensing temperature, cold water from the collectors is circulated through the condenser. Throughout the condensation the temperature in the adsorber decreases until the condensation stops because the temperature difference between adsorber and condenser is not sufficient anymore. It could be shown that this mode of operation is feasible and makes sense when no other heat sink is available.

## 5. ADSORPTION

The adsorption is the more critical operation mode. When space heating is required, the sorption store has to be heated to a certain temperature depending on the desired flow temperature in the heating loop and then kept at that temperature until the space-heating loop is shut off. The key parameter is the available temperature lift that depends strongly on the current water content of the adsorber and to a lesser extent on the steam pressure. At very low water contents the temperature lift is very large. That means that very low condensing temperatures are sufficient to reach the desired store temperature. As more and more water gets adsorbed, this temperature lift decreases rapidly (see figure 5).

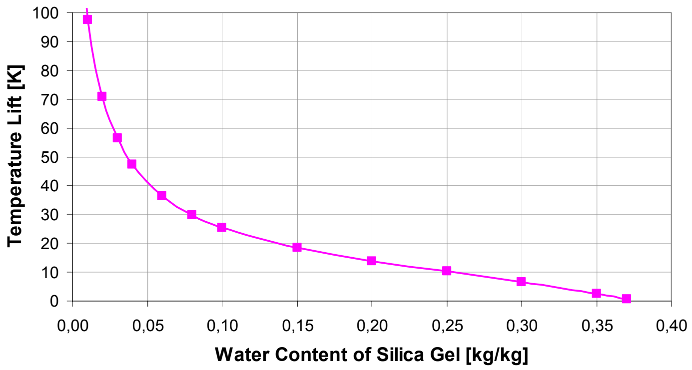


**Figure 5: Available temperature lift as a function of water content of the silica gel at an evaporator/condenser temperature of 20°C**

For the test run shown in figure 6, a constant set temperature of the store of 42°C was assumed which is likely to be the maximum required for a low-temperature heat distribution system. To do that, water is led into the bottom of the storage tank and evaporated by heating the evaporator/condenser heat exchanger. The evaporated water is adsorbed on the silica gel and generates heat that is removed into the space-heating loop through the adsorber heat exchanger.

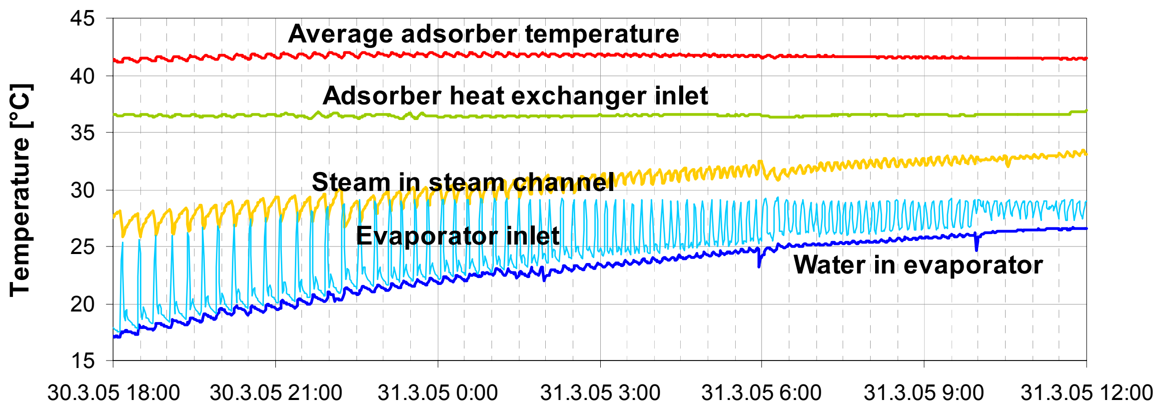


**Figure 6: Adsorption test with constant adsorber temperature**

Figure 6 shows the temperature of the water in the evaporator at the bottom. This temperature increases because the temperature for evaporation that is necessary to reach the desired 42°C of adsorber temperature increases with increasing water content. The oscillating curve above is the inlet temperature to the evaporator. This temperature oscillates because the electrical heater in the evaporator circuit was turned on when the adsorber temperature was below the desired value and turned off when the adsorber temperature reached the desired value. The curve in the middle is the temperature of the steam measured in the middle of the vertical steam channel in the center of the adsorber. At the top of the diagram the average adsorber temperature is shown which is very constant and below the flow temperature going into the space heating loop. The temperature difference of about 5 K between the adsorber and the flow temperature shows that the heat transfer within the silica gel is very poor although the transferred power was only 400 W during this experiment.

## 6. CONCLUSIONS

The new compact system design for a sorption storage system has shown an improved operation of the sorption principle. Pressure and heat losses within the system could be reduced significantly.

However, the most critical point remains the available temperature lift during adsorption. The sorption heat storage principle has a number of disadvantages compared to a standard solar combisystem using a water-filled storage tank.

1) An additional heat exchanger between storage tank and space heating loop is needed which has a significant temperature loss because of the low heat conductivity of silica gel.
2) Sensible heat losses of the sorption store because it has to be heated from ambient temperature at the beginning of adsorption operation and has heat losses to the ambient after operation stops.
3) For storage of low temperature heat for evaporation an additional (conventional storage tank) is needed. Therefore the complete system will consist of a conventional storage tank and one or more sorption storage tanks. There is more hydraulic piping needed in comparison with a standard solar combisystem which leads to increased piping losses.
4) A sorption storage system operates mainly as a thermally driven heat pump. That means that only a very small portion of the heat is actually stored (at least with the material combination silica gel – water). Most of it has to be supplied for evaporation during discharging, even if it is at a low temperature level. For a working range between 2 and 12 % water content, approximately 88 % of the adsorption enthalpy has to be supplied for evaporation.

These disadvantages lead to the conclusion that a sorption storage system cannot efficiently be used for short-term storage. The advantage of storage without thermal losses (separation of adsorbent and working fluid) can only make an impact if it is used for longer-term storage. At the same time the material pair has to deliver a sufficient temperature lift that compensates the disadvantages mentioned above.

The available temperature lift of silica gel and water as working pair is only sufficient with water contents of approximately 2 – 12 %. This is significantly less than the total adsorption potential of 35 kg water per 100 kg of silica gel. That means that the energy density that can be reached with this material is much lower than previously thought and much larger storage volumes would be necessary.

Figure 7 shows the heat of adsorption of several adsorbents as a function of the water content. The silica gel used in the experiments described in this paper is silica gel Grace 127B. It can be seen that its adsorption enthalpy is just above the evaporation enthalpy of water for water contents above 12 %. Only at low water contents there is a significant binding energy and therefore significant temperature lift available. There are materials with higher adsorption enthalpies available. Very high adsorption enthalpies mean that very high temperatures are necessary for desorption which can be a problem for solar applications. An ideal adsorbent would have an elevated evaporation enthalpy over a wide range of water contents. Some of the materials shown in figure 5 show good characteristics but are still very expensive or have other disadvantages such as corrosiveness.

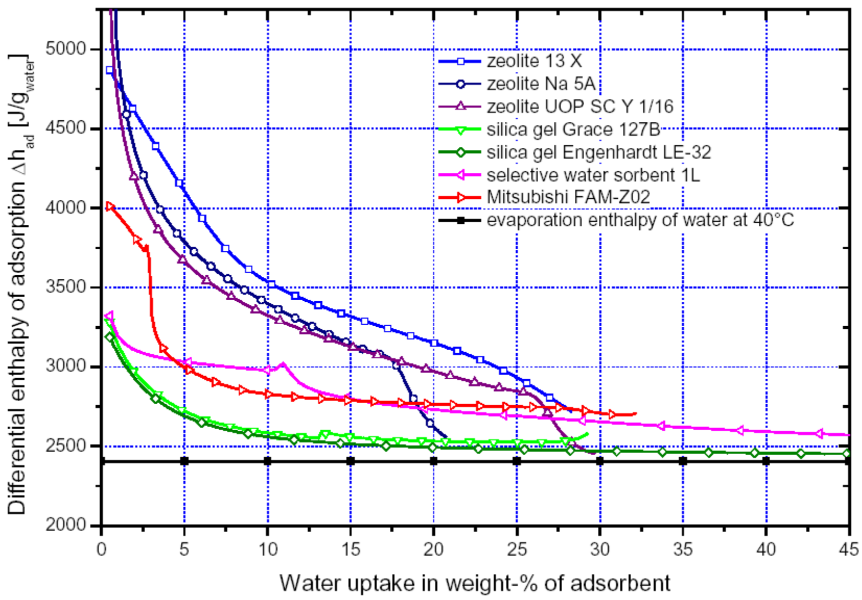


**Figure 7: Differential heat of adsorption vs. water content of adsorbent from Hadorn (ed.), 2005**

Therefore, it will be the task of future projects to find a material combination that fulfill the requirements of sorption systems for storage purposes.

1) Higher temperature lift over a larger range of water contents
2) Higher binding energy (i.e. more energy actually stored)
3) Higher energy density
4) Better heat conduction to reduce temperature losses across heat exchangers.

## ACKNOWLEDGMENTS

We wish to express our appreciation to the European Commission, the Austrian Ministry for Transport, Innovation and Technology and the Austrian Federal State of Styria for funding the project MODESTORE.

## REFERENCES

Gartler, G., Jaehnig, D., Purkarthofer, G., Wagner, W. (2004): Development of a High Energy Density Sorption Storage System, Proceedings of the EuroSun Conference, Freiburg, Germany.

Hadorn, J.-C. (ed., 2005): Thermal energy storage for solar and low energy buildings - State of the Art - June 2005, Servei de Publicacions Universidad Lleida, Spain.

Núñez, T., Henning, H.-M., Mittelbach, W. (2003): High Energy Density Heat Storage System – Achievements and Future Work, ISES Solar World Congress, Göteborg, Sweden.

Núñez, T. (2001): Charakterisierung und Bewertung von Adsorbentien für Wärmetransformationsanwendungen, PhD thesis in physics, Albert Ludwig Universität Freiburg im Breisgau.

Welteroth, J., Mittelbach, W. (2001): Final Report HYDES Project. Final Report of a Joule III Project, European Commission.