Long-term thermochemical heat storage for low temperature applications

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Abstract

The development of compact and efficient seasonal solar thermal storage based on sorption technology is of key importance for a year around supply of renewable heat for domestic buildings. Possible storage materials are zeolite or salt containing composites. Several crucial process parameters have to be considered: possible energy density, environmental impact of used materials, mechanical resistance of the storage materials, and humidity supply for adsorption. An open sorption moving bed adsorption reactor was found to be a suitable device for this application, together with a hot air solar installation.

Keywords: heat storage, sorption, seasonal storage, laboratory prototype

1. Introduction

The development of compact and efficient seasonal solar thermal storage based on sorption technology is of key importance for a year around supply of heat for domestic buildings. With loss-free seasonal heat storage, it is possible to increase the share of solar thermal energy in room heating and hot tap water toward 100%. In principle, water storage can be used for this purpose but considerable heat losses to the ambient will occur. The use of a thermochemical storage principle can greatly reduced the system size (collector area and storage volume) to obtain the same or even an improved thermal performance but makes necessary the development of a reliable and economical technical setup.

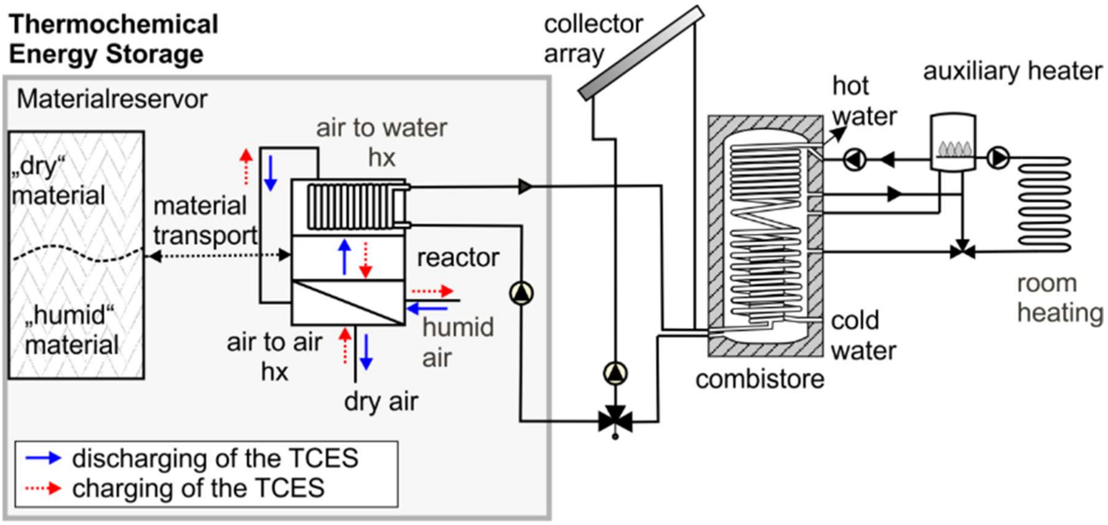

Fig. 1: Schematic of a possible concept of a long-term heat storage in a domestic building (Kerskes, et.al. 2012)

Tab. 1: List of critical boundary conditions for thermochemical energy storage for domestic buildings

Critical boundary condition	Impact on application
Energy and raw material requirement for storage material production	Energetically amortisation of the system Costs of the system

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Desorption characteristics of the storage material	Required temperature of desorption Energy storage density
Adsorption characteristics of the storage material	Required humidity for adsorption Reachable application temperatures
Mechanical properties of the storage material	Reactor design
Sophisticated control strategy including forecast of weather profiles and forecast of demand	Proper storage material handling to avoid shortage or breakdown
Power to drive the adsorption process	Clear advantage compared to heat pump is required for market penetration

The development of a thermochemical storage concept (see Figure 1) is generally based on the adsorption characteristics of the storage materials (isotherms). This characterization can indicate whether or not a material is suitable for a desired application in terms of energy. Beside this, several other aspects have to be taken into account (see Table 1): reactor design to reach temperatures for desorption, capable humidity source to generate adsorption heat, mechanical stability for lifetime, process control to avoid male function, and not least the monetary and energetic amortization of the application.

2. Setup and Measurements

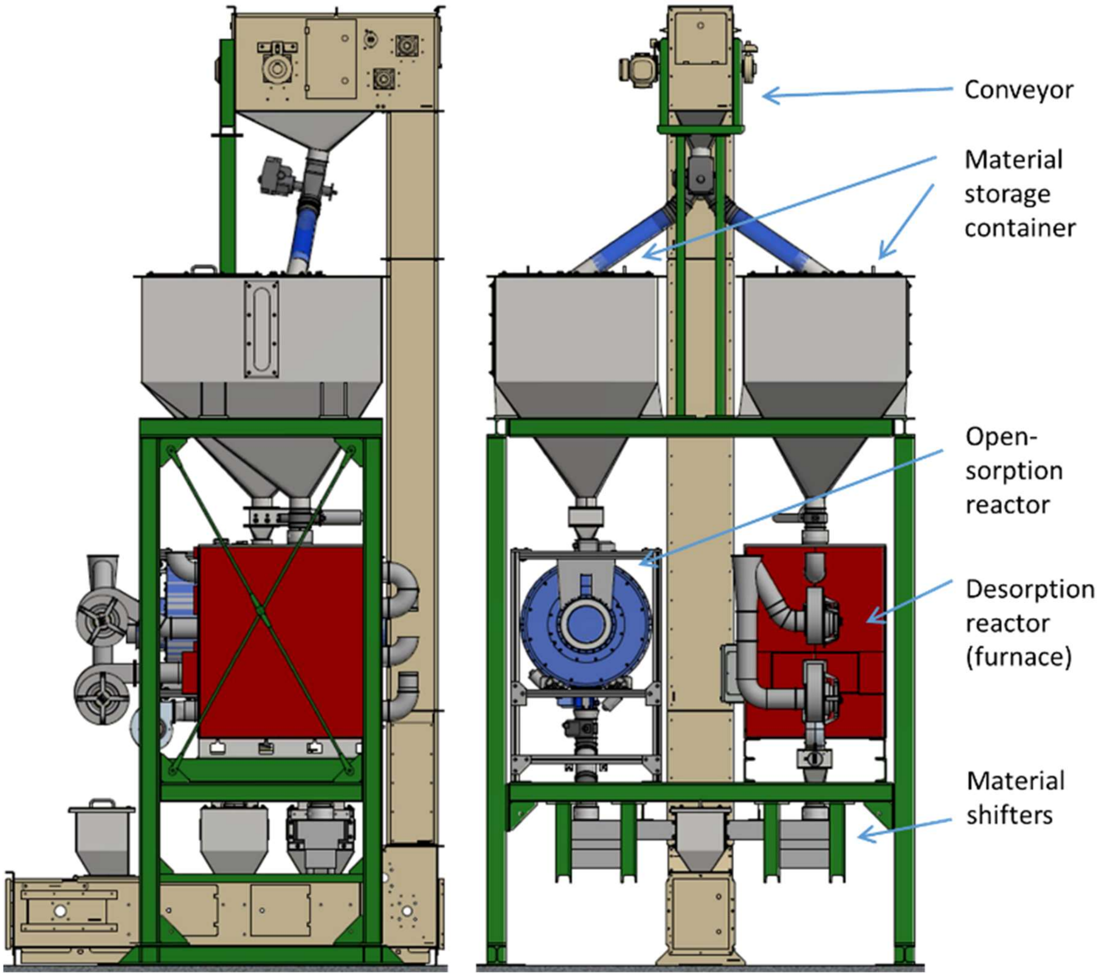

Fig. 2: Schematic of the built prototype

Process principle

Already in the 1980s a research group at ZAE Bayern (Germany) was investigating a sorption store operating in an open process. First demonstration plants using zeolite has been realized then (Hauer, 2002). For the present concept (see figure 2), the open process reactor was adapted for a kind of agitated (mixed) bed in order to guarantee a uniform material humidification. With this feature, it is possible to not only use molecular sieves (zeolite) as storage materials but also salt composite which are more difficult to handle due to their different water uptake behavior. The principle of the adsorption process is explained using figure 3: The process airflow enters the reactor from the left into the fixed inner cylinder, entering the zeolite bed via openings covered by mesh ware at the bottom. The process air crosses the zeolite bed in upward direction transferring humidity to the zeolite grains and gaining heat from the released adsorption enthalpy. At the free space directly at the top of the outer cylinder the hot air is guided into a chimney like tube, down again and to the left chamber and exit of the inner cylinder in direction of heat exchanger in order to be used and as source for room heating.

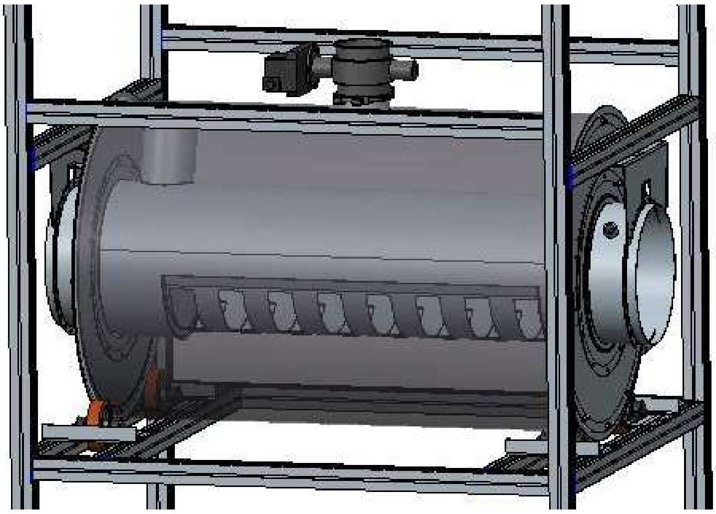

Fig. 3: Schematic of the installed adsorption reactor, outer part is rotating, inner part is fixed

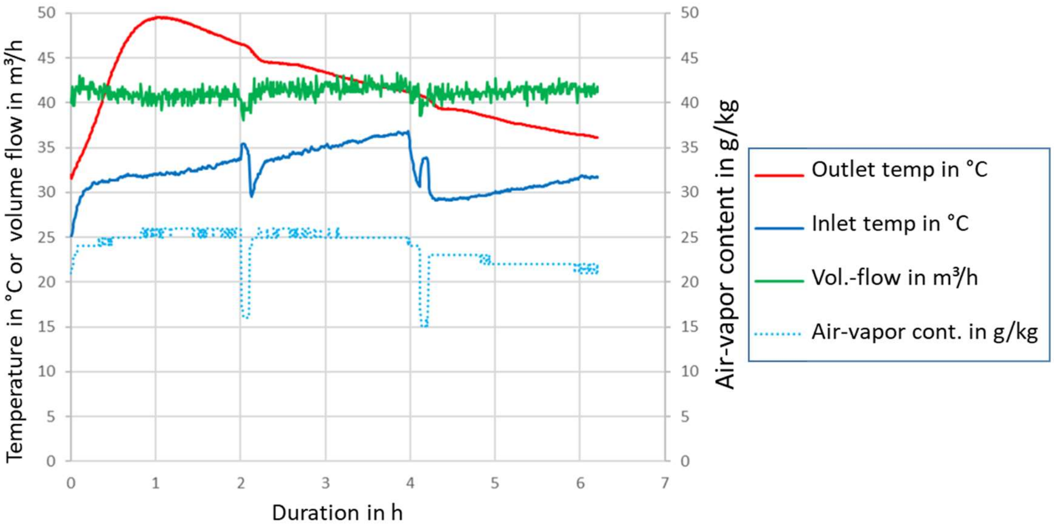

Fig. 4: Data from adsorption process, the process airflow (dotted line) shows depressions due to dust evolvement

Figure 4 shows the temperature elevation of the process heat while passing the zeolite bed over a period of 6 hours.

The consequent desorption (humidity reduction) of the zeolite, takes place in the adsorption furnace (figure 5) if excess heat is available from the solar thermal hot air installation (figure 7): the granular material moves from top to bottom (at a mass flow rate of 2…20 kg/h) passing several arrays of heating channels that establish four temperature zones. At first, a preheating process starts around the tube bundle heater at the top. Second, the desorption process by warm air passing through the material from one of the channels to another (blue circle in figure 5-left). Figure 6 illustrates the corresponding temperature evolvement. Over time the pre-heating temperature (blue line) and the zone 2 temperature leads to about 80°C in the material. In zone 3 the highest temperatures show up (red line). The final value of about 200°C lead to a material humidity at around 8%. This zone can be heated by additional electrical heaters of there is no support from the solar thermal installation. Last step is the cooling by the bottom tube bundle that delivers heat to the top (green line)- The material that leaves the furnace to meet the conveyor is already cool again (black line).

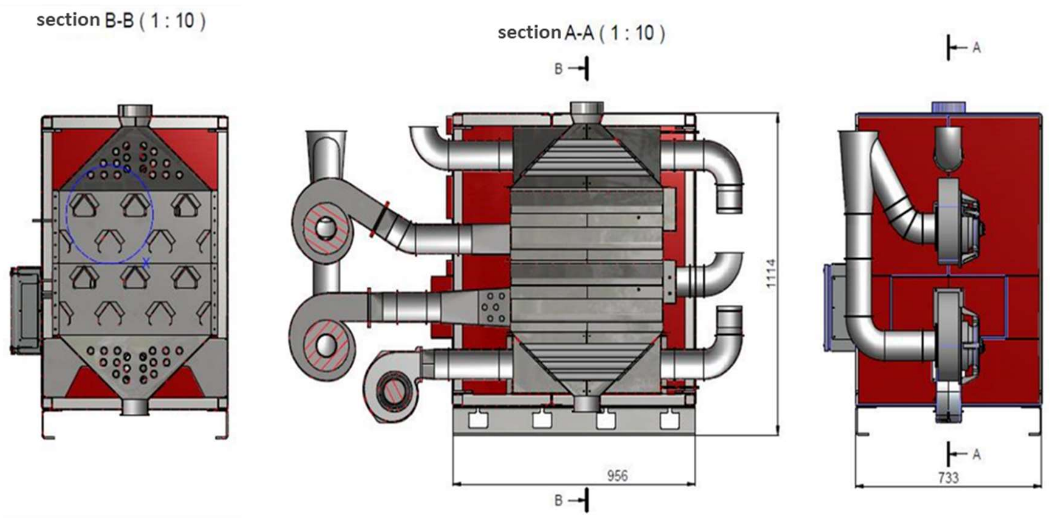

Fig. 5: Schematic of the installed solar hot air desorption furnace

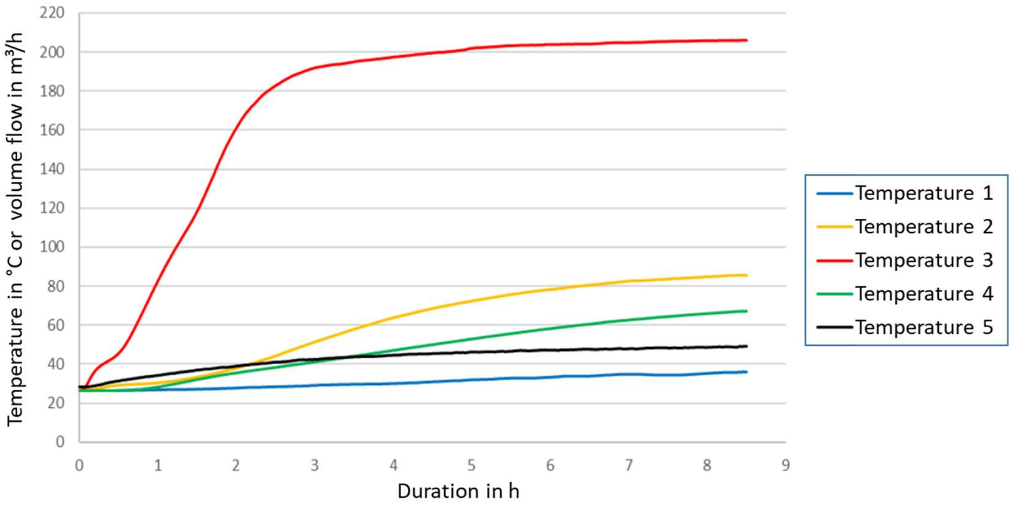

Fig. 6: Date from desorption process in the furnace (electrically powered), temperatures 1 to 5 are measured from top to bottom of the furnace

The conveyor was installed in order to guarantee a save and preserving material transportation to the material storage compartments at the top. Nevertheless some problem occurred by dust evolvement inside the rotating adsorption reactor. Dust was transferred by the process air to the outgoing channels but also by the material transfer into the conveyor.

Energy conversion

The thermal source to support the storage system is a solar thermal installation working with air. The installation provides sufficient high temperature during summer to desorb the material as much as possible. The desorption grade is dependent on air temperature, ambient humidity, airflow, and period.

During winter conditions when heat is used for space heating (ambient temperature <10°C, solar irradiance <200W/m²), the solar installation (figure 7) provides pre-heated and humidified air for adsorption. Humidification is required since cold winter air contains quite low water vapor amounts (typ. 4-6g/kg at 5°C ambient temperature) and is not able to reach sufficient temperature during adsorption therefore.

Fig. 7: Pictures of the installed solar hot air installation

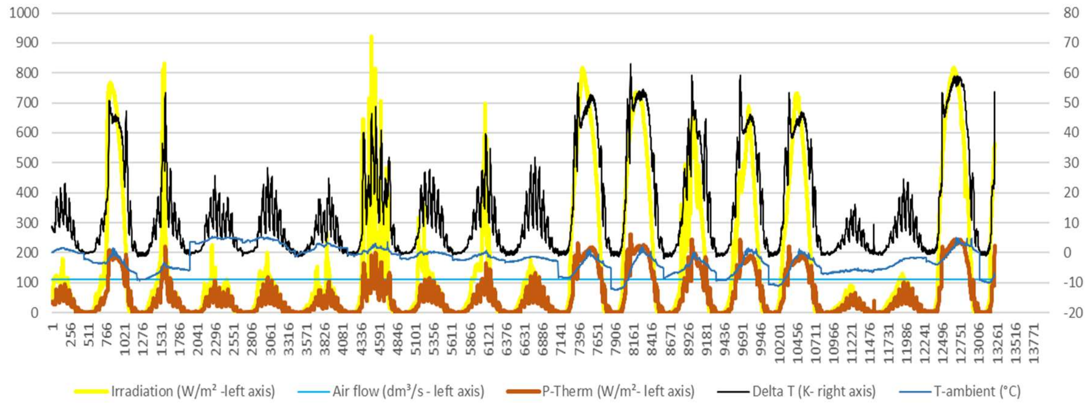

Fig. 8: Measured weather and collector data in a sequence of 18 days during 3nd to 21st of January 2016 at the University building in Wels/Austria, nighttime hours are omitted, daily maximum irradiance varies between 100W/m² (foggy weather) to 900W/m² (clear weather).

During the adsorption process, the material adsorbs the provided humidity of the air as far as the material itself reaches saturation. This process leads to a temperature elevation of the storage material and the bypassing air depending on the water vapor content of the input air. To reach a temperature of 45°C of the air for space heating for example, an air enthalpy (based water vapor and heat content) in the range of 40kJ/kg is required of the input air to the reactor is required. Figure 9 shows the Moliere-diagram for the typical situation for adsorption heat release.

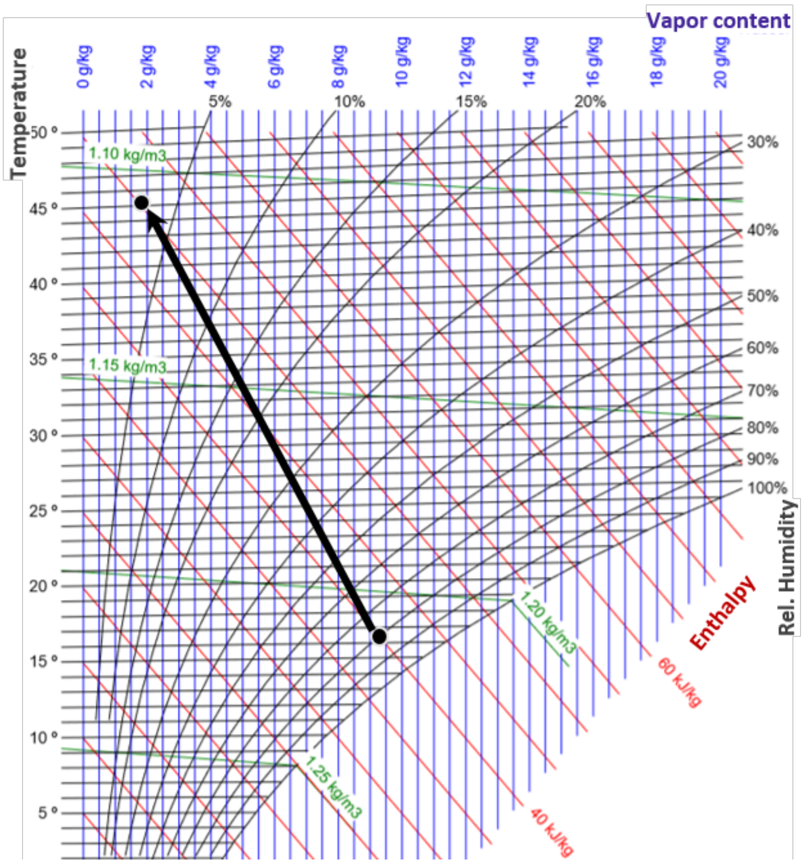

Fig. 7: Mollier diagram illustrating the state change of the air during adsorption heat release

In addition to the tests and measurements, also modelling and simulation were performed in order to proof the technical concept. In particular the prove of a special model for the moving bed adsorption (rotating adsorption reactor) with measurement data was done. This model was built on the idea of a fully mixed reaction bed in contrast to fixed bed reaction with crossing reaction fronts. Results of the simulation is presented separately (Daborer-Prado, 2019).

References

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