SORPTION COLLECTOR – PERFORMANCE INCREASE OF CLOSED ADSORPTION STORAGES

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1 SUMMARY

The conventional storage system, consisting of a main storage and an evaporator/condenser heat exchanger connected to a water reservoir, was extended by a new innovative component. The so called sorption collector is used to increase the storage density based on the charge boost process. The collector prototype is a special designed vacuum tube collector filled with zeolite 13XBF. The charge boost process uses the pressure difference between two storages (main and sorption collector) at different temperature level to dry the material to a higher level compared to the conventional desorption. The sorption collector shows an achievable energy density of >200 kWh/m³ at a temperature of 150 °C due to the repetition of the charge boost mode. The maximum measured bed temperature during experiments in a sunny week in January was 115 °C in the sorption material and > 200 °C on the outside of the bed. The high temperatures measured show the potential of the sorption collector. The higher the temperature in the collector during day the higher energy density can be achieved. During night it shows a significant temperature and hence also a pressure drop in the collector which is necessary to have an efficient charge boost.

2 INTRODUCTION

Thermal energy storage is needed whenever there is a time discrepancy between energy production and energy demand. This time discrepancy is the main challenge for renewable heat sources, since their production is inconsistent or at periods with low heat demand there is a strong need for thermal energy storages, which store heat in times of overproduction and release the heat in times of heat demand. [Hauer A. et al, 2013]

Solar heat in combination with a seasonal storage has the potential to cover 100 % of the heat demand of buildings with completely renewable energy. To store heat efficiently for such a long period of time there are following requirements for the storage technology to fulfil: high energy density to keep the system compact; low losses to store heat for a long period of time, a long lifetime and they need to be cost efficient to compete with alternative energy production.

A technology which can fulfil the mentioned requirements is the thermochemical energy storage. Compared to sensible storages, they have literally no heat losses during long storage periods and a 3-times higher energy density [Köll R. et al, 2017a]. Nevertheless, the system size needs to be further reduced and at the same time there is a need to significantly reduce the investment costs of the system.

A new technique called “charge boost” was developed, which enables a further increase of the energy density and efficiency of the system at lower desorption temperatures [Mette B. et al, 2013]. This also contributes to a significant cost reduction of investment costs. The charge boost is applied after a complete desorption of two sorption storage vessels. Whereas the main storage vessel is on high temperature, the second storage vessel, the so called charge boost storage is on a lower temperature level. The resulting pressure difference is used to further desorb the main storage vessel by transferring the vapor from the main storage to the charge boost storage. The charge boost storage needs to be desorbed again afterwards and the charge boost process repeated. The result is a higher state of charge of the main storage, without increasing of the desorption temperature and the process can be repeated.

3 DESIGN

The charge boost mode enables new possibilities to make the sorption storage more efficient. To meet the new requirements of a suitable charge boost storage a new component, the so called sorption collector, was developed. Therefore, the sorption material zeolite 13XBF was filled into stainless steel pipes with a diameter of 97.8 mm. In the center of the stainless steel pipe a perforated sleeve is placed to keep a free space to improve the vapor transfer within the zeolite bed. Five stainless steel pipes are welded to a vacuum manifold which is connected to the storage system. On the steel pipes, double copper pipes are placed which are connected to the hydraulic system and enable the conventional use of the collector. On the copper pipes a sydney-type glass pipe is placed and fixed on the top and bottom of the collector because of the relatively high weight. In addition the sorption collector is equipped with mirrors on the backside to increase collector performance [Köll R. et al, 2017b]. The design is shown in Figure 1. In total the collector has an aperture area of 3.05 m² and contains 35 kg of zeolite 13XBF in the inner vacuum pipe, which is used for charge boost purposes.

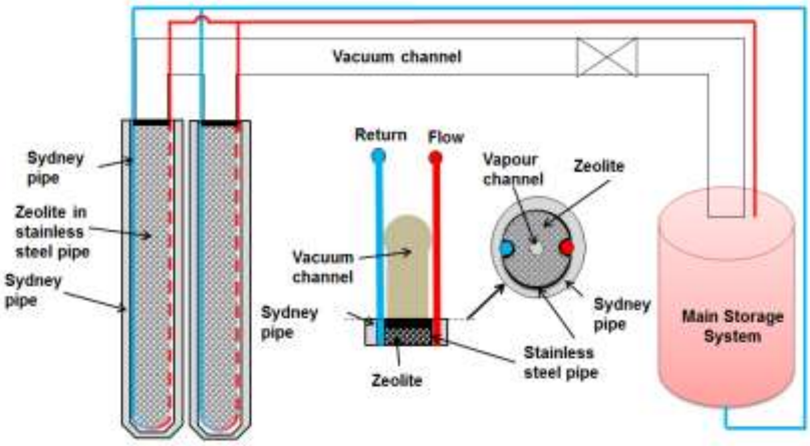


Figure 1: Concept of sorption collector applied as charge boost storage

The sorption collector is operated in a day/night cycle (see Figure 2). During the day the collector is used to heat up the main storage by transferring heat via the hydraulic system and the fixed bed heat exchanger in the sorption storage module. At the same time the sorption material in the collector is heated up and the released water vapor is condensed at the condenser heat exchanger. The main advantage during this step is that the collector sorption material is directly desorbed in the collector and therefore reaches the highest possible temperature. Additionally no extra containment is needed and the system can be built in a compact way.

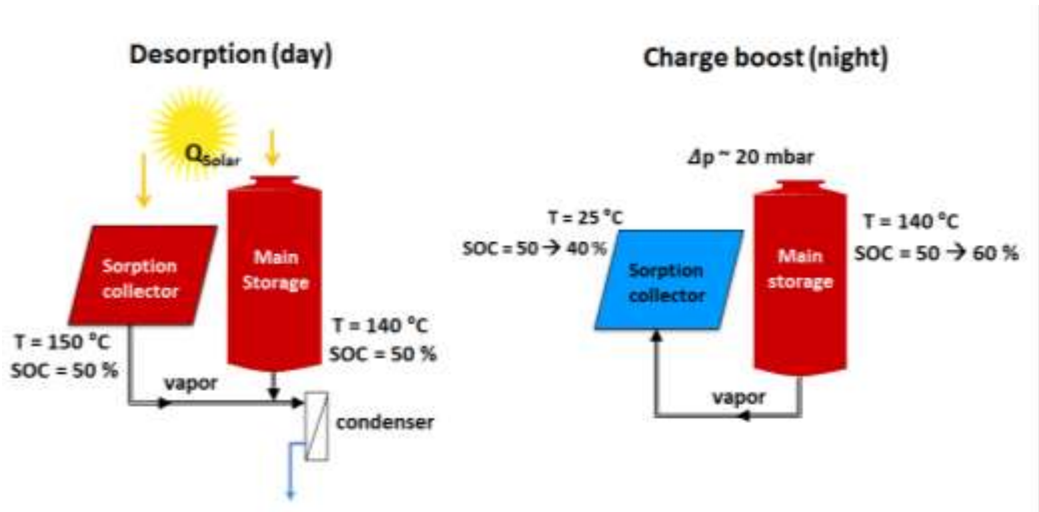


Figure 2: Working principle of the sorption collector under typical boundary conditions

During the night the charge boost mode can be applied. Therefore the high radiation losses of the collector are used to cool down the collector sorption material, which also induces a pressure drop. The resulting pressure difference between sorption collector and main storage is used to further desorb water vapor from the hot main storage to the cold sorption collector. This means that during the charge boost step the vapor is shifted to the sorption collector, but on the next sunny day it can be desorbed easily. The main advantage during this step is that the main storage can be desorbed to a higher state of charge, compared to a conventional desorption, without increasing of the desorption temperature. The sorption collector provides the ideal boundary conditions for this application because it enables high temperatures during day and cold temperatures during night.

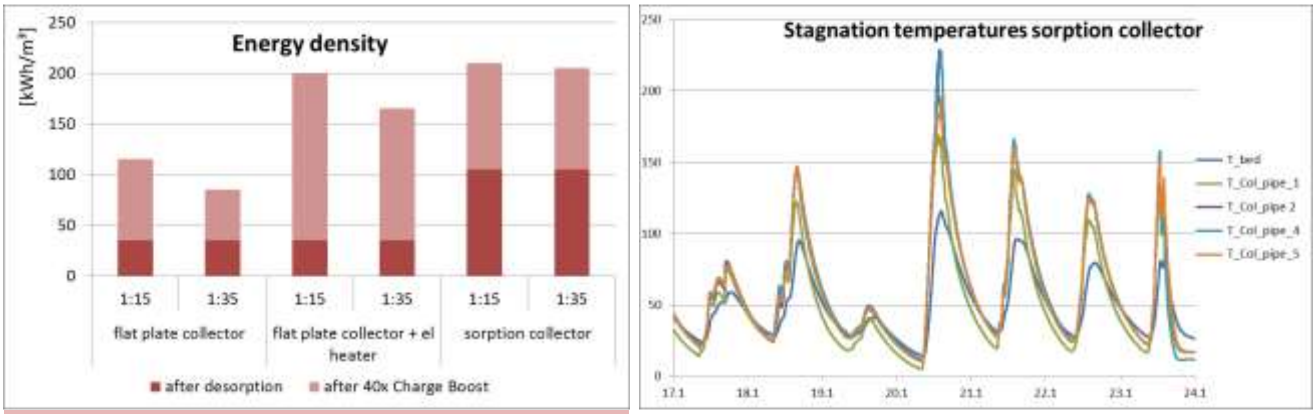
4 METHODE

A prototype of a sorption collector was designed and built up in the laboratory. It is filled with zeolite 13XBF and implemented in the complete storage system. Experiments were carried out with the prototype to investigate and optimize the collector, as well as the system performance.

Figure 3: Developed prototype of sorption collector with glass tubes

5 RESULTS

The performance of the sorption collector is tested experimentally under variation of the boundary conditions. First test results show that the thermal performance of the collector is not negatively influenced by the sorption material in the construction, but the storage system performance can be improved significantly. Due to the charge boost technique the storage capacity of the zeolite could be used more efficiently and hence the energy density can be improved significantly. In Figure 4 the potential of improvement of the energy density by repeating the charge boost is shown.



Temperatures	Flat plate collector	Flat plate + el heater	Sorption collector
main storage	80	80	150 °C
charge boost storage	80	180	150 °C

Figure 4: Left: Improvement of the energy density based on repeating the charge boost mode compared to the conventional desorption at the same temperature under different mass ratios between charge boost storage/sorption collector and main storage and different use cases (temperatures). Right: Measured stagnation temperature of the prototype sorption collector

In any use case the energy density can be doubled at least. The highest energy density can be achieved with the sorption collector combination, which achieves an energy density of > 200 kWh/m³. Also the combination of a flat plate collector and an electrical heater driven e.g. by PV electricity, is also a good alternative, achieving between 170 – 200 kWh/m³ (depending on the size).

The measured stagnation temperature show temperature peaks of > 220 °C on the outer side of the zeolite bed and 115 °C in the zeolite bed. The temperature difference between inside and outside is due to the low heat conductivity of the material and needs to be improved to achieve the highest possible temperatures in the sorption bed for a successful desorption. It can be also seen that due to the high radiation losses of the collector during the night the bed temperature drops to 20 – 30 °C during night and hence also a significant pressure drop is occurring, which is the ideal condition to perform the charge boost process. This way the day-night cycle can be used most efficiently.

6 CONCLUSION

The energy density achieved with a sorption storage system depends on the temperatures available for drying. The charge boost technique enables a more efficient charging of the storage system at the same available temperature. The potential of the sorption collector is very high. At an assumed temperature of 150 °C in the collector material an energy density of > 200 kWh/m³ can be achieved. Compared to a conventional flat plate collector where only 110 kWh/m³ can be achieved. With the prototype a peak bed temperature of 115 °C could be measured, but the temperature on the outside of the bed was above 200 °C which shows that with improvement of the heat transfer in the collector the temperature and hence also the energy density can be even higher than assumed for the calculation.

Due to the breaking of the glass during operation of the hydraulic system, only the stagnation temperatures could be measured. The reason for the breaking of the tubes during the operation of the hydraulic pump was that at higher temperatures in the pipes the thermal expansion caused some mechanical stress on the glass pipes and caused the breaking. The construction was reinforced to prevent the braking afterwards. Due to several changes in the construction to prevent the braking of the glass pipes, the sensors to measure the bed temperature were not positioned at a proper position any more. Therefore the bed temperature during the later experiments could not be measured precisely. Nevertheless, the measured temperatures on the outside of the bed show the potential of the bed temperature even in winter and therefore the potential of high energy density. The charge boost principle could be proven, but to achieve the full performance of the sorption collector the heat transfer in the fixed bed needs to be improved.

7 REFERENCES

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