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Limitations imposed on energy density of sorption materials in seasonal thermal storage systems

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Abstract

Extensive work is undertaken in search of new materials suitable for thermal sorption storage. High energy capacity is the all sought after goal. In most cases this translates to a high maximum water vapor uptake. While this is notably important, in the system development and operation additional factors become strong contributors to the success or failure of a seasonal thermal storage system. Included are, the required system charging temperature. In domestic applications temperatures below 100 °C are most fitting to the existing building solar collector infrastructure. Further charging limitations can result from possible material characteristics such as crystallization. Just as critical as charging is discharging. It is precisely at this point where much can be gained or lost. In discharging the temperature difference between the minimum absorber temperature and the minimum evaporator temperature is critical. A low temperature difference between these two temperatures permits low resulting sorbent concentrations and thus a high accessible capacity. In a system application, these temperature levels are not freely chosen. These considerations lead to highly varying operation results in both output temperature and concentration. In this paper insight is given in respect to a sorption demonstrator plant based on sodium hydroxide as sorbent and water as sorbate.

1. Introduction

Energy density is a key criterion for the viability of sorption storage compared to solely sensible bases heat storage. Nevertheless precisely this parameter is heavily depending on operating conditions, making simple comparison virtually impossible. Major parameters are the temperatures in charging, discharging, condensation and evaporation. Naturally system engineering factors are also highly influential, but will not be further focused on in this paper. The liberty in operating parameters in material research can be the source of discrepancy between the ideal storage capacities indicated by material researchers and that resulting in system applications. It follows that the comparison of heat storage materials becomes very difficult. The actual operation of a sorption system under real conditions often leads too much lower energy densities than initially propagated. In order to prevent misleading indications in the theoretical capacity, a careful study of the sorbent vapor pressure vs. temperature diagram of a given sorbent is important, taking into account the application dependent system parameters. Indicated expected energy densities must be accompanied by assumed operation parameters. For the application of domestic seasonal solar thermal storage in Switzerland, the following operational parameters are suggested:

- Solar collector temperature: max. 95 °C.
- Heat sink temperature: max. 35 °C.
  This temperature depends on the type of heat sink; atmosphere, ground, water, etc.
- Discharging source temperature: min. 5 °C.
- Space heating return temperature: 26 °C,
  Corresponding to floor heating.
- Domestic cold water: 10°C
- Sorbent storage temperature: min. 10 °C. The sorbent material is stored in the facility of the house, possibly in the basement.

It remains to be clarified to what extend these parameters are applicable to other countries and regions with possible seasonal storage applications.

Nomenclature

T	Temperature
ω	Concentration

Indices

A	Absorber
C	Condenser
D	Desorber
E	Evaporator
h	High (ω_{seh}: solution with high sorbent concentration)
in	In
l	Low (ω_{sel}: solution with low sorbent concentration)
out	Out

2. Practical application with sodium hydroxide

Sodium hydroxide is a readily available, well known and widely used base [1]. It has a high affinity to water at temperatures coinciding to solar thermal collectors, space heating and domestic hot water. In the presented approach, sodium hydroxide serves as sorbent and water as sorbate. Due to its precise characterization, sodium hydroxide is an ideal forerunner for the development of seasonal sorption storage systems. At our institute intensive development of such a sorption storage system has been undertaken. System commissioning is in progress. In this work much experience has been gained in respect to the general challenge of sorption storage systems. In the next two subchapters insight is given through the analysis of the vapor pressure vs. temperature diagram of aqueous sodium hydroxide, in respect to the operational limitations defined in the introduction, followed by initial operation results from the demonstrator.

The mentioned demonstrator is built as a closes liquid sorption heat storage system, base on a continuous but not full cycle absorption heat pump process. Closed relates to operation under exclusion of all non condensing gasses, at water vapor pressures coinciding to the respective temperature. Liquid sorption refers to the aggregate state of the sorbent in the system. This is kept in a liquid state at all times. For this reason concentrations beyond 50 wt% sorbent in sorbate are prevented due to the risk of solidification at temperatures below 10 °C. Continuous makes reference to the cycle of absorption and desorption of the sorbent and the sorbate. Not full cycle indicates the separate process of desorption in the charging process during the worm season and absorption in the discharging or heating process during the cold season. The system has a single annual cycle. It operates as a heat pump, not storing actual heat, but the potential to regain heat at elevated temperatures from a low temperature heat source [2].

In figure 1 the read line indicates a possible charging process. For sodium hydroxide the solar heat source is generally not the limiting factor. For this reason, a charged state sorbent concentration of 50 % is assumed in further discussions. The charging process is not indicated in figure 2.

As indicated, operating in the manner of a sorption heat pump, the sorption heat storage has a sorbent concentration dependent temperature lift. In the case of a 50 % sodium hydroxide concentration in water, the maximum theoretical temperature lift is approximately 38 K. The output temperature of the sorption storage is thus highly dependent on the maximum sorbent concentration and the minimum temperature in the evaporator. In this and all further discussions herein, thermal and pressure losses in operation are not accounted for. In the following subchapters operation is elaborated on in respect to the vapor pressure vs. temperature diagram of aqueous sodium hydroxide at different concentrations.

2.1. Performance for space heating

When considering operation for space hating, if the evaporator temperature $T_{Eout} = 5$ °C as proposed in the introduction, then the absorber temperature can have a maximum temperature of approximately $T_{Aout} = 43$ °C. For areal space heating such as floor or wall heating, this is sufficient. In general maxim temperatures of about 35 °C are required. Now in respect to system storage capacity, the return temperature of the heating system is significant. This translates to the absorber temperature T_{Ain}. T_{Ain} coincides to the degree of water vapor uptake in respect to the evaporator temperature T_{Eout}. High water vapor absorption, prompting high energy density, is reached by low increase in temperature from T_{Eout} to T_{Ain}. Nevertheless, both parameters are operation dependent. In figure 1 the blue line indicates the discharging processes according to the defined parameters. The return temperature of the areal heating system $T_{Ain} = 26$ °C limits the maximum discharge concentration to 38 %. From this a storage capacity in respect to the diluted sorbent of approximately 250 Wh / l is reached.
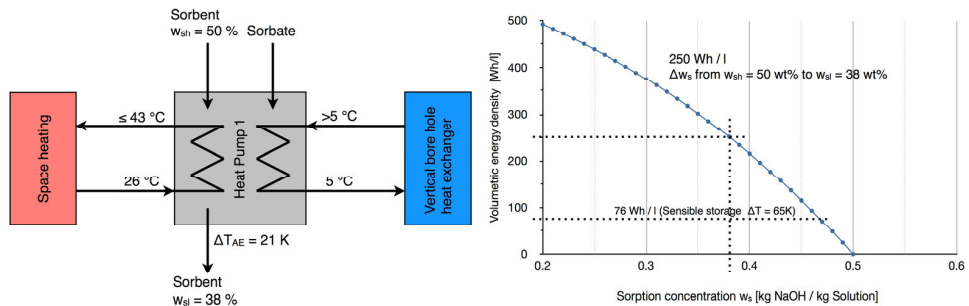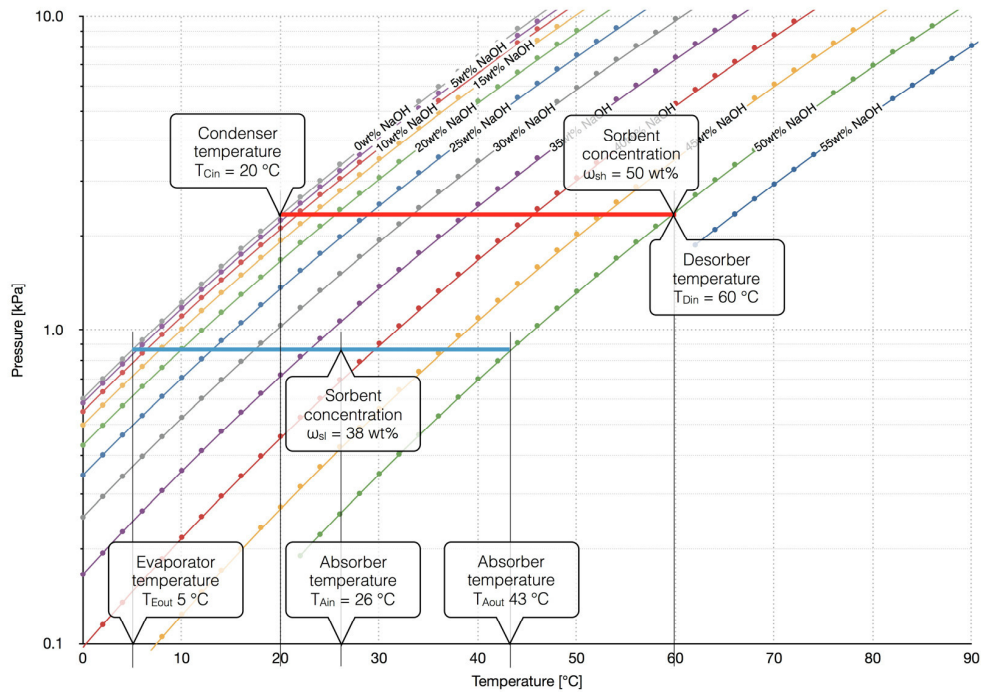
Fig. 1. Vapor pressure versus temperature diagram of aqueous sodium hydroxide at varying concentrations. Indicated is the possible charging process and the discharging process in respect to the set temperature limitations for space heating.

2.2. Performance for domestic hot water

When considering the production of domestic hot water from domestic cold water the process is as illustrated in figure 2. The domestic cold water is assumed to have a temperature of 10 °C, the temperature of the evaporator remains at T_{Eout} = 5 °C. Due to the considerably lower temperature of the domestic cold water to the return temperature of the areal heating, the sorbent can be diluted to a greater extend. Sorbent concentrations of 20 % can be reached. This in turn results in a greater overall system heat capacity of approximately 490 Wh / l. Note that the output temperature remains at T_{Aout} = 43 °C. This is possibly insufficient for domestic hot water.
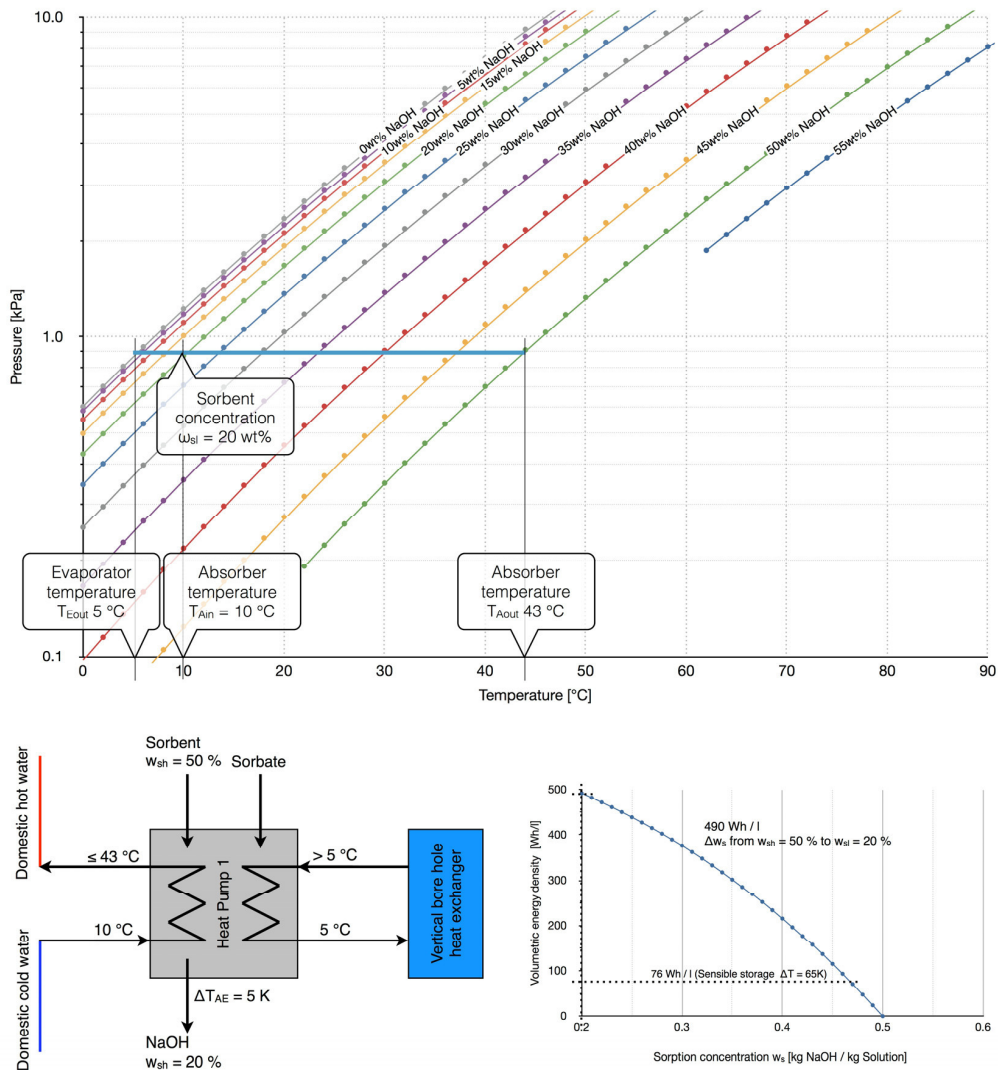
Fig. 2. Vapor pressure versus temperature diagram of aqueous sodium hydroxide at varying concentrations. Indicated is the discharging process for domestic hot water in respect to the set temperature limitations.

3. Conclusion

In this paper it has been shown that both output temperature and capacity are highly dependent on the operational parameters. In order to prevent misleading indications assumed operating parameters must be indicated. It is naturally most preferable that these parameters are fitting to the actual system environment. Such system parameters for Switzerland have been proposed. It remains to be validated to what extend these can be globally applied.

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References

[1] Olsson J., Jernqvist A,. Aly G. Thermophysical Properties of Aqueous NaOH-H_2O Solutions at High Concentrations. International Journal of Thermophysics. Vol. 18, No. 3. 1997

[2] Fumey B., Weber R., Gantenbein P., Daguenet-Frick X., Williamson T., Dorer V. Closed sorption heat storage based on aqueous sodium hydroxide. Energy Procedia 48 (2014) 337 – 346