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Realization of a 4kW thermochemical segmented reactor in household scale for seasonal heat storage

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Abstract

Replacing fossil fuel by solar energy as a promising sustainable energy source, is of high interest, for both electricity and heat generation. However, to reach high thermal solar fractions and to overcome the mismatch between supply and demand of solar heat, long term heat storage is necessary. A promising method for long term heat storage is to use thermochemical materials, TCMs. The reversible adsorption-desorption reactions, which are exothermic in the hydration direction and endothermic in the reverse dehydration direction, can be used to store heat. A 250L setup based on a gas-solid reaction between water-zeolite 13X is designed and tested. Humid air is introduced to a packed bed reactor filled with dehydrated material and by the resulting adsorption of water vapour on TCM, heat is released. The reactor consists of four segments of 62.5L each, which can be operated in different modes. The temperature is measured at several locations to gain insight into the effect of segmentation. Experiments are performed for hydration-dehydration cycles in different modes. Using the temperatures measured at different locations in the system, a complete thermal picture of the system is calculated, including thermal powers of the segments. A maximum power of around 4kW is obtained by running the segments in parallel mode. Compactness and robustness are two important factors for the successful introduction of heat storage systems in the built environment, and both can be met by reactor segmentation. With the segmented reactor concept, a high flexibility can be achieved in the performance of a heat storage system, while still being compact.

Keywords:
Thermochemical heat storage; Open sorption system; Water-Zeolite; 250 L Pilot; Segmented packed bed reactor

1. Introduction

In Europe, energy consumption for domestic purposes accounts for almost 40 % of the total energy demand [1]. Therefore, in this sector, a significant potential exists to reduce fossil fuel consumption. Energy storage is a key step to shift to renewable energy sources, which are inherently intermittent. Solar energy, as one of the most exploitable renewable energy sources, is available more than required in residential houses during summer, while the demand

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cannot be met during winter. A solution is to store excess of solar energy in summer using a so-called thermal battery, which can be discharged to provide heat for the residential demand in winter [2].

A promising method is heat storage in thermochemical materials (TCM), by which heat can be stored in a compact and quasi loss-free way over a long time. In the thermochemical heat storage process, heat is stored into an endothermal dissociation reaction (charging), and, at a later time, the energy can be retrieved from the reverse exothermal reaction (discharging), according to the reaction $A(s) + B(g) \leftrightarrow AB(s) + heat$. Heat generated by a solar collector during summer can be employed to desorb water from the material. The energy stored in this way can be released during winter by introducing water vapor to the dehydrated material.

An interesting material should be non-toxic, non-corrosive and stable with fast reaction kinetics and high energy storage density [3]. A good candidate fulfilling these requirements is zeolite. Although zeolite is expensive to be used in a full scale seasonal heat storage, it is still a good candidate to be used in scientific studies because of its stability. In recent years, intense research has been performed on innovative system designs to integrate the thermochemical concept into an overall system, and lab or pilot scale setups are developed and tested. Table 1 presents some of the zeolite based prototypes that have been reported, along with operating conditions and energy densities.

Table 1: Prototypes along with operating conditions for open and closed systems.

project	material	charge temp. $[^oC]$	discharge temp. $[^oC]$	energy density $[kWh/m^3]$	max. power $[kW]$
MONOSORP [4]	70 kg zeolite 4A	170	20	120	1.5
STAID [5]	80 kg zeolite 13X	180	20	114	2.25
E-HUB/ECN [6]	150 kg zeolite 13X	185	25-60	58	0.4

The *MONOSORP* [4] prototype is developed based on zeolite honeycomb structures called monoliths instead of the ordinarily employed packed beds. The monoliths are made by extrusion of zeolite 4A into integrated shaped bodies with a large number of small straight channels inside. The main advantage of using such a material bed is low pressure drop. However, the monolith production adds up to the material cost. With an inlet temperature of about 20^oC and a humidity of $6g/kg$ (gram of water to kilogram of air) a maximum temperature lift of around 22^oC is achieved.

The *STAID* [5] prototype is a system consisting of two reactor segments, where zeolite 13X spherical particles are packed. The system can provide a maximum thermal power output of around $2.25kW$ during $6h$, with a maximum instantaneous COP (considering only electrical consumption during the hydration process) of 6.8. The inflow air has a relative humidity of around 70% at 20^oC, which corresponds to a water vapor pressure of about $16mbar$ or an absolute humidity of about $10g/kg$. This high value for the inlet humidity is the reason for the achieved high power.

The *E-HUB/ECN* [6] prototype is a system consisting of two packed bed reactor segments working with zeolite 13X. This system is developed such that it can provide thermal power at higher temperature compared to the above-mentioned systems. In this setup, an air-to-air heat exchanger is employed in order to preheat the inflow air by the residual heat in the outflow air. An inlet humidity of $12mbar$ water vapor pressure is applied. Air leakages inside the system lead to a low thermal power output from the system.

In this work, the implementation of thermochemical heat storage in the built environment utilizing solar thermal heat is investigated. Therefore, the operating conditions are chosen based on the application. Specifically, the inflow air should be conditioned carefully regarding the humidity, because the inflow humidity has a large effect on the output of the system. The segmentation concept is used in order to reduce heat losses. A large scale high power pilot is realized, consisting of four segments. Each reactor segment contains a $62.5L$ packed beds of the zeolite 13XBF material. The packed bed reactor design is chosen because of its simplicity and low cost, while the pressure drop over the bed is reduced by reducing the height-to-width ratio of the bed. The reactor segments are placed in a system with other components. Air leakage and high pressure are tried to be avoided in different parts of the system. Experiments are performed on the pilot in order to determine the energy storage density, demonstrate the power and calculate the COP. Recommendations are given for further studies on the pilot and for improvements.