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Behavior of scaled-up sodium alanate hydrogen storage tanks during sorption

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ABSTRACT

Sodium alanate is being experimentally tested in scaled-up quantities. For this purpose, several tanks have been designed and constructed. The tank functionality during absorption and desorption of hydrogen was demonstrated in a scale of 8 kg of alanate, with a peak technical absorption time below 10 min. The absorption and desorption data show good reproducibility. Neutron radiography was used in another tank to show the powder's physical behavior during sorption, showing conservation of the macroscopic structure during cycling.

1. Introduction

Hydrogen as an energy vector has been discussed as the most promising alternative to fossil fuels, with a special emphasis on its storage [1,2] for some time. Since no known storage method or material has been able to reach the targets set either in Europe or in the USA for light-duty vehicles [3,4], this is still an important research field. However, the focus has shifted lately from basic investigation into materials to more applied systems [5]. In this frame, development and scale-up of known materials into practical tanks and systems starts to take precedence. In this work, the behavior of two tanks, one with ~8 kg and the other with ~100 g sodium alanate is presented. The first one was designed and built in the frame of the EU STORHY project and is being thoroughly tested within another EU project, NESSHY. The design, as well as simulation results regarding its sorption behavior has been published elsewhere [6,7]. The type of tank selected was a different one from similar efforts in the USA [8], since a tube-and-shell construction with the alanate in the tubes, although somewhat heavier, would lead to better heat transfer and avoidance of hot spots, with better kinetics as a result. Since demonstration of good kinetics was the main driver of the design at the time, the compromise reached between hydrogen sorption kinetics and tank weight was a good one. This has been vindicated by the hydrogen sorption results shown here, which represent the main novelty of the work. The authors are aware of a tank along similar lines to the one described here being tested in the USA, and expect interesting insights from the forthcoming publication.

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2. Material and methods

The hydrogen storage material used in this work was sodium alanate doped with $TiCl_3 \cdot AlCl_3$, following the synthesis described elsewhere [9,10]. A full description of the tank design, steel used, and other parameters, has already been published [6].

For the testing of the 8 kg alanate tank and subsequent designs, a new lab has been designed and built. In order to maximize safety, the testing chamber was equipped with explosion-safe devices, as well as a venting system for over-pressure events. Fig. 1 shows the tank connected to the testing setup inside the explosion-resistant testing chamber.

The lab contains all measuring equipment (pressure gauges, mass flow controllers, thermocouples), as well as the electronics, valves, computer system and the auxiliary equipment. This consists of two subsystems: a hydrogen supply subsystem for pressures up to 130 bar using hydrogen of 99.999% purity and a heat transfer system for operation temperatures up to 180 °C. The standard operation conditions are $p_{max} = 100$ bar and $T = 125$ °C for charging; $p_{min} = 0.2$–10 bar and 160–175 °C for discharging the tank. In order to measure the hydrogen absorption curves shown below, the tank is brought to the operational temperature of 125 °C by means of the heat transfer system using an oil flow of ~130 kg/min. Then, mass flow controllers let the selected flow of hydrogen pass into the tank, so that the pressure increases up to the desired level (100 bar). During the whole procedure, hydrogen flow, pressure and oil temperature are monitored and recorded at intervals of 0.5 s. For the hydrogen desorption, the procedure is similar, with the difference that the temperature is 160 °C and the hydrogen flow reverses its direction, coming out of the tank. When a pressure of 0.2 bar g is reached and the flow of hydrogen negligible, the data acquisition is stopped.

3. Results and discussion

The design of the 8 kg alanate tank was optimized regarding the minimization of hydrogen charging time [6]. The goal in this respect was a charging time of less than 10 min for 80% of the capacity. Fig. 2 shows that this has been achieved in the 12th absorption. Cycles 1–10 were activation cycles and are therefore not considered here.

In this figure, it can be seen that the charging process is divided into three regions: one from 0 to 0.5 wt%, where the charging speed is highest, one from 0.5 to 2.1 wt%, which shows a somewhat lower charging speed, and one from 2.1 to the final capacity of 3.7 wt%. The first region corresponds to an increase in pressure inside the tank vessel, without chemical reaction. The second region is due to the first step of the reaction leading to the formation of Na_3AlH_6 (combined with a further increase in pressure), while the third region accounts for the second step of the reaction leading to the formation of NaAlH4 and the increase to the final pressure of 100 bar.

Both capacity and speed of charging are in good agreement with previous data from lab-scale reactors [9,11] and milligram scale samples measured in Sieverts' – type apparatus, showing that the scale-up of the system does not have adverse effects on its behavior, and indicating that further scale-up is possible without degradation of storage properties.

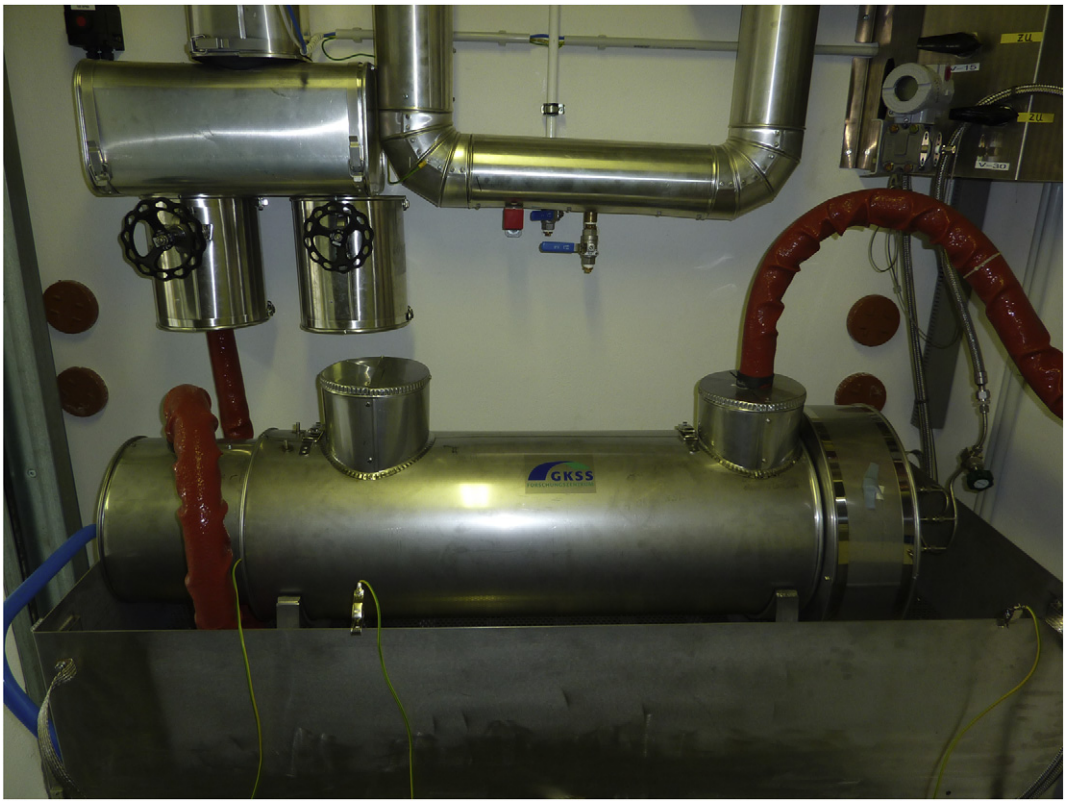

Fig. 1 – 8 kg alanate hydrogen storage tank connected to the testing setup in the explosion-protected lab.