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Development of a Real-Time Hydrogen Level Detection System for Storage Cylinders

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Abstract: *The development of a real-time hydrogen level detection system for storage cylinders is a crucial innovation aimed at enhancing safety, efficiency, and reliability in industries utilizing hydrogen as a fuel source. As hydrogen continues to gain prominence in applications like fuel cell vehicles and energy storage, ensuring the accurate monitoring of hydrogen levels within storage cylinders is vital. This system leverages advanced sensors to continuously measure and display key parameters, such as hydrogen concentration, pressure, and temperature, enabling real-time monitoring and quick response to any critical changes. By integrating this technology into existing systems, operators can proactively manage hydrogen storage, ensuring safe usage and optimized performance.*
Commercial applications usingcomplex metal hydrides are limited, especially for thermolysis-based systems where so far only demonstration projects have been performed. Hydrolysis-based systems find theirway in space, naval, military and defense applications due to their compatibility with proton exchange membrane (PEM) fuel cells. Tank design, modeling, and development for thermolysis and hydrolysis systems as well as commercial applications of hydrolysis systems are described in more detail in this review. For thermolysis, mostly sodium aluminum hydride containing tanks were developed, and only a few examples with nitrides, ammoniaborane and alane. For hydrolysis, sodium borohydride was the preferred material whereas ammonia borane found less popularity. Recycling of the sodium borohydride spent fuel remains an important part for their commercial viability..

Keywords: hydrogen storage; complex hydrides; modeling

I. INTRODUCTION

This project focuses on creating a Hydrogen Level Detector that uses pressure and temperature sensors to determine how much hydrogen is left in a storage tank. The system works by measuring the pressure inside the tank using a pressure sensor and the temperature using a temperature sensor. These two measurements are then used to calculate the mass of hydrogen remaining in the tank using the Ideal Gas Law.The Ideal Gas Law relates the pressure, volume, temperature, and the amount of gas in a system, allowing us to calculate the hydrogen mass based on the current conditions inside the tank.

Once the hydrogen mass is determined, the system also calculates the remaining energy in kilowatt-hours (kWh) by multiplying the mass of hydrogen by its Lower Heating Value (LHV), which is around 33.33 kWh per kilogram. Finally, the calculated hydrogen mass and energy are displayed on a digital interface, providing real-time data that can be easily monitored. This system allows for accurate tracking of hydrogen levels, ensuring that the fuel is used efficiently and that the user always knows how much hydrogen is available. By continuously measuring and displaying these values, the Hydrogen Level Detector provides an effective tool for managing hydrogen-powered systems, whether in vehicles, power plants, or other applications that rely on hydrogen as a fuel source.

Over the last 15 years complex aluminum and boron hydrides have been investigated as possible hydrogen storage materials [1–39]. Although the composition of these materials seems to be similar, the chemical behavior is entirely different. Several complex aluminum hydrides (NaAlH4, KAlH4, and Na3AlH6 etc.) can be decomposed at elevated temperatures and rehydrogenation is possible under technically relevant conditions using catalysts [40-150]. However,

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the decomposition temperature for complex boron hydrides (LiBH4, NaBH4) is often much higher and reversibility cannot be observed under conditions used for complex aluminum hydrides [150-180]. Consequently, complex aluminum hydrides can be used for technical applications where rehydrogenation of the hydrogen storage material is an important prerequisite [181-254]. In contrast, complex boron hydrides are favored for disposal cartridge systems, releasing hydrogen in a hydrolysis reaction at ambient temperatures. These different properties result in completely different engineering as well as technical requirements. This makes the development of suitable tank systems based on aluminum or boron hydride compounds challenging. This review describes recent research in the development of tank systems based on complex hydrides for thermolysis and hydrolysis. Thermolysis requires a heat input and care must be taken in the design of the storage tank in order to effectively distribute the heat. Hydrolysis, on the other hand, requires not only effective mixing of the complex hydride and water but also separation of the produced hydrogen gas and the slurry consisting of the decomposition product and water. While thermolysis tank systems are developed in demonstration projects, hydrolysis tank systems have already found real life applications. The review is divided into two parts, the first focuses on thermolysis, while the second concerns hydrolysis. Initially, reactor, kinetic and system models will be introduced in each part. Hereafter, specific examples with the most common complex aluminum or boron hydrides are given together with their applications.

II. RELATED WORK-THERMOLYSIS

Development of a hydrogen storage tank based on complex hydrides involves different levels of research. The first level provides a screening of materials at laboratory scale. Once relevant candidates have been selected, a methodology to evaluate their performances must be established. The evaluation is based on two steps. The first one is modeling of the full-scale system and the second one is manufacturing of a prototype to experimentally evaluate the performance of the material and validate the results of the simulation. The Department of Energy (DoE) in the United States of America has given several milestones for the research on the optimal complex hydride/tank design pair (Table 1). All these technical specifications are material dependent, thus the first screening starts with a selection among available complex hydrides. Nevertheless, improvement of the scale-up system through several strategies is still possible. Among all the complex hydrides claimed for hydrogen storage, just a few of them have been chosen to develop a full-scale tank system. Since Bogdanovi´c and Schwickardi discovered that sodium alanate can reversibly store hydrogen using a Ti-based catalyst [4], its hydrogen storage properties have been widely studied. The absorption/desorption mechanism has been found to occur through a two-step process (Equation (1)). Another system based on a mixture of magnesium nitride and lithium hydride

III. ARCHITECTURE OF THE PROPOSED IOT SYSTEM

The diagram illustrates a system for flood monitoring and data logging using various electronic components. The system uses an ESP8266 microcontroller to manage the process. It measures the distance using an ultrasonic sensor and the temperature and humidity with a DHT11 sensor. The measured distance is compared to a threshold to determine if a flood is occurring. If the distance is less than the threshold, it indicates a flood, and the system sends an alert to the cloud. Otherwise, it indicates a safe condition and sends a corresponding message to the cloud. The temperature and humidity values are displayed on an OLED screen and sent to Thing Speak for data logging and visualization as graphs.
The hydrogen level detector project involves several key steps. First, pressure and temperature sensors are used to measure the pressure and temperature inside the hydrogen storage tank. The pressure sensor provides a voltage reading, which is calibrated and converted into pressure values (Pa), while the temperature sensor gives a reading in Celsius, which is then converted to Kelvin. Using the Ideal Gas Law, the remaining hydrogen mass is calculated by considering the pressure, tank volume, gas constant, and temperature. To estimate the remaining energy, the hydrogen mass is multiplied by its Lower Heating Value (LHV) of approximately 33.33 kWh/kg. Finally, the calculated hydrogen mass and energy are displayed on a digital screen, allowing for real-time monitoring of the hydrogen levels and energy in the tank. This methodology ensures accurate and continuous tracking of hydrogen reserves for efficient management of energy storage.

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IV. MODELLING OF THERMOLYSIS TANK SYSTEM

Lab-scale evaluation of materials for hydrogen storage differs significantly from tank development in the kg scale. In order to avoid unnecessary work in the development and construction of metal hydrides tank systems, modeling is often used as a starting process for tank evolution. Simulations are therefore performed to optimize tank design and operating parameters, but also to allow evaluation of the complete performances. For the modeling of a tank system based on complex hydrides, three sub-processes that occur during hydrogen sorption require implementation in the calculations: (i) hydrogen transport,

(ii) chemical reaction and (iii) heat transfer. Hydrogen transport and heat transfer are modeled through mass, momentum and energy balance equations and all simulation are performed using the same assumptions and equations. Chemical reactions are modeled using empirical kinetic models; therefore the next section focuses on the different models found in the literature. After the final model is proposed, parametric studies can be performed to gain insight into the influence of different parameters on the system performance.

The first step in building a kinetics model is determination of the dehydrogenation mechanism of the considered material. Once the mechanism is known, the rate for each step is defined by a general model parameterized using three variables: the temperature T, the conversion _, and the pressure p (Equation (5)) [10]:

V. BLOCK DIAGRAM & DESCRIPTION OF HYDROGEN STORAGE SYSTEM

Bellosta von Colbe et al., demonstrated the functionality of an 8 kg tank during absorption and desorption with a peak technical absorption time below 10 min, thereby validating the design and simulation work carried out previously .The ease of use, speed of charging, and reproducibility of results of the 8 kg sodium alanate tank were highly promising . This has paved the way for the application of complex hydrides based hydrogen storage tanks wherever a source of available waste heat is compatible with the energy needs of the tank (especially regarding the temperature level). This is the case especially in large scale and stationary applications. Utz et al., studied the behavior of a powdered bed containing NaAlH4 doped with 4 mol % CeCl3 in a lab-scale hydrogen storage tank with flow-through mode. The results showed a significant influence of the cooling by excess hydrogen on the flow-directional temperature profiles. The initial thermal conductivity of the bed increased by a factor of 1.3 compared to values reported in literature (0.67 W_m_1 _K_1). This caused significantly lower temperature peaks in the center of the reaction bed. The value for the permeability decreased by 50% and led to increase in the pressure drop. No cycling.

degradation after 36 cycles was observed and a storage capacity of approx. 3.9 wt % H2 was reached with this material [39].Modularity was a key concept in the design of a General Motors R&D/Sandia National Laboratories hydrogen storage system (Figure 1). The system was designed to be refueled in approximately 10 min and to deliver hydrogen at up to 2.0 g_ s_1. A heat amount of 60 MJ had to be removed during refueling by means of a circulating heat transfer fluid. However, for hydrogen delivery, heat must be supplied to the hydrogen storage system in-situ and this was achieved by means of a catalytic heater [27]. Urbanczyk et al., designed a hydrogen storage tank based on 2.7 kg of NaAlH4 doped with 4 mol % TiCl3 that was thermally coupled with a high temperature proton exchange membrane (HT-PEM) fuel cell (Figure 2). The waste heat of the fuel cell was used to heat up the storage tank during dehydrogenation, which was consequently fed into the fuel cell. The desorbed amount of hydrogen gas was enough for 3 h of fuel cell operation and the system produced 940 Wh of cumulative energy [37]. Na3AlH6 doped with 4 mol % TiCl3 was used as a storage material in an Al-alloy tank system developed at IUTA (Institut für Energie- und Umwelttechnik, Germany) and Max-Planck-Institut für Kohlen forschung, in order to decrease the overall weight, (Figure 3). The hexahydride was operated at a lower pressure compared to NaAlH4. The heat transfer was realized through an oil flow in a bayonet heat exchanger, manufactured by extrusion molding from an aluminum alloy. The 0.21 kg hydrogen storage tank released and absorbed 3.6 g (1.7 wt %) of hydrogen at approximately 450 K. A test with 45 cycles (hydrogenation and dehydrogenation) was carried out without any failure of the tank or its components. Operation of the tank under real conditions indicated the possibility for applications with stationary HT-PEM fuel cell systems [38]. The same partners at IUTA and Max-Planck-Institute für Kohlenforschung used Na3AlH6 doped with 4 mol % TiCl3, 8 mol % Al and 8 mol % activated carbon as a hydrogen storage material for a scaled up 1.9 kg Al-alloy storage tank with corrugated heat exchangers. Up to 31 hydrogenation and dehydrogenation cycles were performed

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without degradation. The aim of the demonstration project was to produce a lightweight system that could be connected to a HT-PEM fuel cell. The system could improve efficiency of a combined heat-power unit for household applications hydrogen storage system. Reprinted with permission from reference . Copyright 2012 Elsevier.

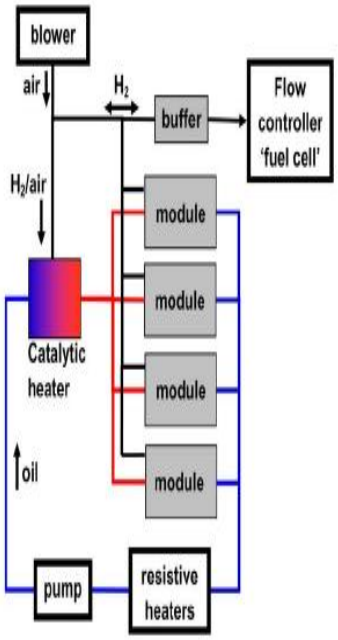

Figure 1. Process flow diagram of General Motors R&D/Sandia National Laboratories

VI. SUMMARY

Implementation: low gravimetric and volumetric capacities, insufficient kinetics within appropriate temperatures and pressure ranges, high cost of the overall engineering system. Modeling provides a powerful tool for the development of strategies and improvement of full-scale tanks. Several studies on tank modeling for thermolysis have been proposed, mainly based on sodium alanate with few examples of others complex hydrides. The main purpose of these simulations was the optimization of some operating parameters (temperature, pressure, thermal conductivity, coolant flow rate and coolant temperature) as well as the tank design (length scale, geometry and fins content). Optimizations were then proposed on the basis of the simulation results. Several modeling tools have been built on the basis of the hierarchical methodology and resistance analysis in order to estimate performances of the system and the limiting factors. The simulations showed that a good thermal management and the limiting factors. The simulations showed that a good thermal management was necessary for the absorption, whereas the pressure control was important for desorption. Still, differences exist between the simulations, which come from the choice of the kinetic model that is implemented as the governing equation for the simulations. Therefore, precautions have to be taken, since the kinetic model is built through experimental considerations. Heat transfer in the metal hydride tank can be improved using heat exchangers, multi-tubular tank geometries and heat transfer enhancers. However, this will also increase the weight of the system. Hence, optimizations are often a compromise between heat transfer and hydrogen content. The strategy based on CH/MH beds could provide a new step in tank design leading to better temperature and pressure management without decreasing the hydrogen capacity excessively. Although ample research has been performed with complex metal hydride materials on small-scale laboratory batches, considerably fewer full-scale thermolysis tanks/systems have been developed and analyzed. Improving the ratio between the mass of the complex metal hydride bed to the mass of the tank wall, by screening lighter materials for the tank wall and developing hydrogen storage materials exhibiting both higher gravimetric and volumetric storage properties, should be a goal in order to obtain lightweight storage systems. There

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are several design principles that must be taken into account while developing a complex metal hydride storage tank, such as packing arrangement of the material, hydrogen supply, heat transfer to the heat transfer medium, effective heat conductivity of the metal hydride bed and volume expansion. Additionally, efficient removal of the reaction heat from the metal hydride tank during refueling and how to provide heat during hydrogen delivery to the fuel cell remain an unsolved problem. Thermolysis of complex metal hydrides has yet to demonstrate the fulfillment of the DoE requirements (Table 1). Especially concerning the gravimetric capacity of approximately 1.5 wt % and
refueling time of 10 min. In hydrolysis, recycling of the spent fuel remains the single biggest challenge. For NaBH4, it requires the recycling of NaBO2 back into NaBH4, either starting from dry NaBO2 or through the use of a regenerative fuel cell. This often means additional costs cannot be avoided. Hence, the use of NaBH4 for portable applications becomes less attractive. As the byproduct from the hydrolysis reaction can decrease the catalyst efficiency, flow reactors holds the biggest potential for reaching commercial applications as these allow to collect the byproduct in a separate tank. The flow reactor with a _-shape design contained a gas channel for more efficient collection of the hydrogen gas. This design may also improve larger scale systems without sacrificing the overall volume and mass of the system. A batch reactor for hydrolysis is simple and does not allow for major design changes. Indeed, batch reactors are probably best suited for convenient tests of new catalysts and for small systems, where volume constraints do not allow for a second tank for collection of the byproduct. Implementation of a conical bottom in the batch reactor was shown to have a positive effect on the hydrolysis reaction. Tank modeling for hydrolysis systems has only received limited attention and was mainly performed on systems with a batch reactor. The proposed models concern mainly the transport phenomena and kinetics for the reaction in the liquid. Further research in modeling of flow reactors may help to improve systems meant for applications. Although hydrolysis technology using complex metal hydrides (e.g., NaBH4 and AB) have found its way into UAVs and submarine applications, the majority of these applications are currently still driven by fossil fuels. These application may benefit from the installation of filters to obtain desired the hydrogen purity, efficient drainage of spent fuel, and operation conditions (humidity, vibrations,

VII. CONCLUSION

Several technical barriers still exist for successful implementation of solid-state hydrogen storage systems based on thermolysis for stationary and portable applications and remain a significant challenge for transportation applications. Currently available storage tank systems typically require large volume, high weight, and have slow hydrogen charging/discharging rates and high system cost. Long-term research goals for the complex hydride materials should be to improve the gravimetric and volumetric capacities, to obtain sufficient kinetics within appropriate temperatures and pressure ranges and to lower the cost of the overall systems. It is obvious that commercial success is not only a question of high hydrogen content of hydrogen storage materials. The overall performance of the whole system, consisting of hydrogen storage material, as well as storage tank design and integration of all the components into a technical system, plays a much more important role than one particular property. Taking this into account, engineering developments for the optimization of solid-state hydrogen storage tank systems must be intensified to overcome technical barriers and to construct safe and consumer-friendly system based on renewable energy carriers.

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