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Hydrogen risk mitigation by catalytic recombiners

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The widespread introduction of hydrogen as an energy source can currently be observed in many countries. The reason for this is the broad applicability of hydrogen in connection with the provision of energy. On the one hand, hydrogen can be used as an energy storage medium to balance out the fluctuating contributions from renewable sources such as wind and sun. On the other hand, it can be used to generate electricity, for example by means of fuel cells, as well as thermal power through combustion. In both cases, power production could be CO_2-free and thus contributes to global efforts to reduce the impact of harmful greenhouse gases.

As a technical gas, hydrogen has thermophysical properties whose values differ considerably - sometimes by an order of magnitude - from other gases used in energy technology today, such as natural gas. Some of these properties are of particular relevance to safety (Kotchourko and Jordan, 2002). Firstly, there is the low density (14 times lighter than air), which means that leaks can occur more easily than with other gases. In addition, hydrogen has a very wide ignition range (approximately 7 times wider than for natural gas), which means that flammable mixtures with air can form more easily. While the ignition energy for hydrogen/air mixtures is significantly lower than for natural gas/air mixtures, the high flame speed enables an easier transition to detonations and high combustion pressures.

Due to the aforementioned properties, the use of hydrogen in enclosed spaces and plant areas poses a particular safety risk. While ventilation is a very common measure to reduce the risk of the formation of flammable gas mixtures, so-called catalytic recombiners could contribute to an increase in safety. Catalytic recombiners convert hydrogen into water vapor through a catalytic reaction with the oxygen present in the air. The catalytic reaction occurs before the lower ignition limit is reached or before ignitable mixtures are formed and can thus prevent or dissolve hydrogen accumulations (Fig. 1). Due to their catalytic operating principle, recombiners are considered being passive devices, so that today they are used in particular in nuclear power plants to eliminate quantities of hydrogen released as a result of accidents (Liang et al., 2014).

For optimum placement and dimensioning inside a plant, it is necessary to reliably predict hydrogen accumulations after leakages as well as the operational behavior of the recombiners to be installed. For this purpose, a numerical recombiner model is required that predicts the hydrogen conversion rates as a function of the atmospheric conditions, typically the hydrogen concentration, temperature and pressure. Available models range from device-specific empirical correlations to more mechanistic approaches (Reinecke et al., 2010). The mechanistic approaches consider the following phenomena:

- Catalytic surface processes (adsorption/desorption, reactions);
- Heat and mass transfer processes between the catalyst and the bulk flow;
- Chimney flow induced by density differences in the gas phase.

For a safety assessment, the numerical recombiner model must be linked to a dispersion code, e.g. computational fluid dynamics (CFD), which describes the dispersion of hydrogen after leakage and the interaction of the recombiner with the atmosphere. Approaches already existing in nuclear safety research are now increasingly being transferred to the field of hydrogen technologies.

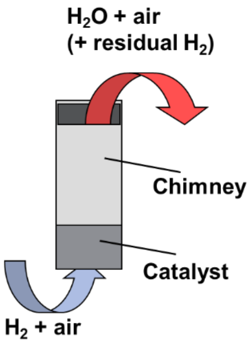

Fig. 1. (left) principle sketch of a recombiner; (right) commercial recombiner for battery rooms.

The maritime transportation of liquefied (cryogenic) hydrogen shows several characteristics that justify the application of catalytic recombiners (Kelm et al., 2021). First, there is the potential of large releases due to the large storage mass. Furthermore, large transport vessels involve several thousands of cubic meters of closed or partially closed compartments with limited ventilation capacities, which require additional measures, e.g. to cope with the accidental failure of safety measures. Finally, long traveling routes in remote regions require measures which can operate autonomously with low or even entirely without power consumption.

The fundamental knowledge gap with regard to the operation of catalytic recombiners in such a scenario is the significantly lower temperatures expected to occur after liquid hydrogen leakage, evaporation and mixing with the atmospheric air. As a consequence, two activities are pursued in the framework of the STACY project (Reinecke et al., 2023). First, a new catalyst is developed, which is specifically tailored for the conditions expected in an accidental hydrogen release on maritime transportation. Second, computational tools to describe recombiner operation at cryogenic temperatures are developed based on data obtained from an experimental program.

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