View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by KITopen

Group: Hydrogen

Hydrogen Risk Assessment for Nuclear Applications and Safety of Hydrogen as an Energy Carrier

Paul Coupe, Andrei Denkevits, Nicolas van Dijk, Olaf Jedicke, Thomas Jordan, Birgit Kaup, Alexei Kotchourko, Mike Kuznetsov, Alexander Lelyakin, Frank Prestel, Maria Stassen, Jianjun Xiao, Zhanjie Xu, Han Zhang

Introduction

In the years 2017 and 2018 the Hydrogen Group continued to develop the in-house CFD HyCodes, GASFLOW and COM3D, and conducted several experimental programs to deepen the understanding of the transient flame acceleration and deflagration-detonation-transition or to provide model validations data. As cryogenic liquid hydrogen has a high potential for supporting the scaling up of applications of hydrogen as an energy carrier, these fundamental phenomena have to be studied also in the low temperature domain. The Hydrogen Group is coordinating the European pre-normative research project PRESLHY to this end. Besides the group has been active in the educational domain by teaching Hydrogen Technologies and managing a related European project NET-TOOLS.

In the application domain a safe catalytic cleaning device for high pressure hydrogen has been developed in the frame of the cooperation with the Instituto Technico Buenos Aires ITBA.

Pre-normative Research for the safe use of liquid hydrogen

For scaling up the hydrogen supply infrastructure the transport of liquefied hydrogen is the most effective option due to the energy density. Especially for the transport sector with the planned large bus fleets, the emerging hydrogen fueled train, boat and truck projects and even for the pre-cooled 70 MPa car fueling, liquid hydrogen (LH2) offers sufficient densities and gains in efficiency over gaseous transport, storage and supply. However, LH2 implies specific hazards and risks, which are very different from those associated with the relatively well-known compressed gaseous hydrogen. Although these specific issues are usually well reflected and managed in large-scale industry and aerospace applications of LH2, experience with LH2 in a distributed energy system is lacking. Transport and storage of LH2 in urban areas and the daily use by the untrained general public will require higher levels of safety provisions accounting for the very special properties. The quite different operational conditions compared with the industrial environment and therefore also different potential accident scenarios will put an emphasis on specific related phenomena which are still not well understood. Specific recommendations and harmonized performance based international standards are lacking for similar reasons.

The Hydrogen Group coordinates the project PRESLHY, which is supported by the European Fuel Cell and Hydrogen Joint Undertaking (FCH 2 JU). The consortium consisting of 10 European research institutions and industry representatives will do research for the most relevant and poorly understood phenomena related to high risk scenarios from 2018 until end of 2010. With the new knowledge generated by this research work science based and validated tools, which are required for hydrogen safety engineering and risk informed, performance based, LH2 specific, international standards will be developed.

Besides the actual coordination the Hydrogen Group of IKET is leading the combustion phenomena work package and conducts an essential part of the experimental program ranging from cryogenic gas dispersion, ignition phenomena to transient combustions phenomena.

So far a review of the state-of-the-art and existing regulations, codes and standards have been conducted. First screening experiments related to ignition by electro-static charge build-up in the accidental cold gas release have been conducted in the test cell Q160.

Cryo-jet ignition by self generated electrostatic charges

The electrostatic field generated by the cryo-jet was measured with a set-up shown in Fig. 19. With the field mills an electrostatic field was identified, which seem to be induced by a cloud of charged particulates carried by the jet. It typically reaches values in the order of 1000 V/m. The particulates must be too small to be seen on the cameras.

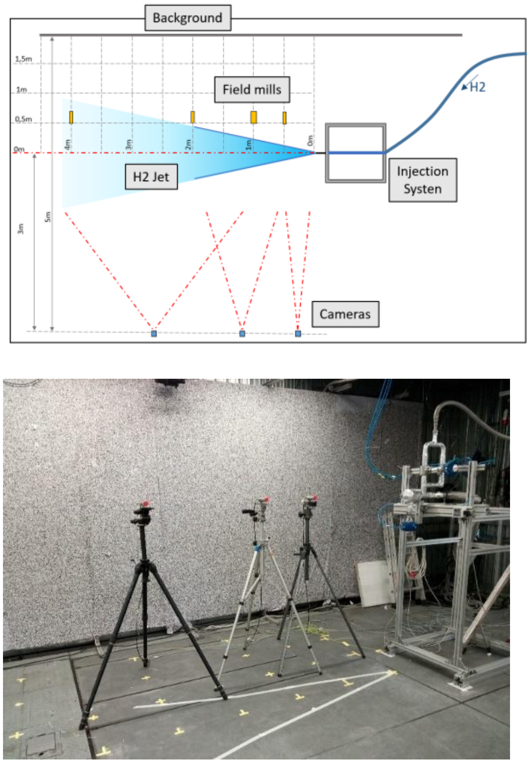

Fig. 19: Experimental set-up of for determination of electrostatic field build-up of cryogenic hydrogen jet releases in test cell Q160 (top: principle view from top experiments; bottom: photography with indicating positions of field mills by red dots)

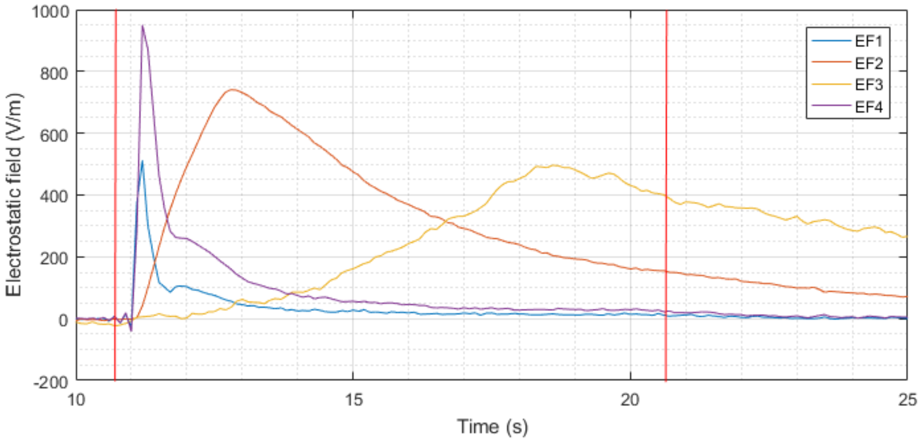

Fig. 18: Recordings of the different Electric Fieldmills (EF) with EF1 close to release point and EF3 at longest distance from release point; EF4 is special field mill with highest sensitivity close to EF1.

As we move further away from the nozzle, the peeks of electric field are delayed in time, and last longer, see Fig. 18. This can be explained by the decreasing velocity of the jet along the central axis. The further away from the nozzle, the longer it takes for the moving cloud to reach, and pass in front of the sensor. The delay and the duration of the peek reduces when the mass flux is increased.

After replacing hydrogen with helium, to exclude material specific issues, similar effects have been observed. Irrespective of the released gas, with sufficiently high ambient humidity and low temperature of the pre-cooled nozzle, ice crystals will form on the release nozzle, see Fig. 21. When the release is initiated the gas will tear of and entrain some small ice crystals. This process involving solid particles and strong shear flow forces is very likely the origin of the electrical charges observed.

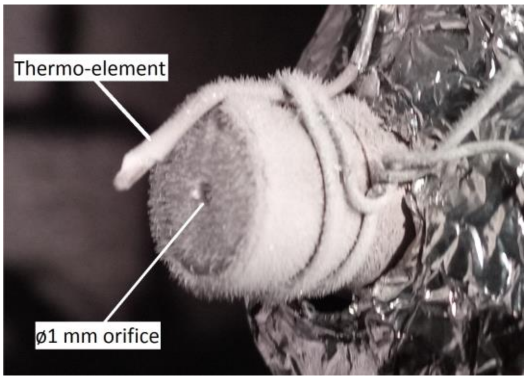

Fig. 21: Pre-cooled release nozzle with ice particles formed on

So, the results of these preliminary test might be summarized as:

- This phenomenon occurs only at cold temperatures of the released gases and with some minimum ambient humidity.
- Then jet carries electrical charges, which might be induced by ice particles formed at the cold nozzle before the actual release (possibly also during the release)

Whether the measured electrical fields are sufficiently strong and effecting the relevant premixed zones of the jet has to be clarified in the sub-sequent test program.

Characterisation of cryogenic hydrogen discharges

Discharge coefficients of cryogenic (T < 120K), high pressure (p < 20 MPa) hydrogen reservoirs will be determined in the DISCHA experiment series (see Fig. 22).

The experiments have been extended to simultaneously investigate the dispersion, ignition and combustion of the released cold hydrogen. This required the installation of an appropriate optical measurement system, consisting of several cameras. The main technique applied for the near field as well as for the far field observations of the cold gas jet behavior will be

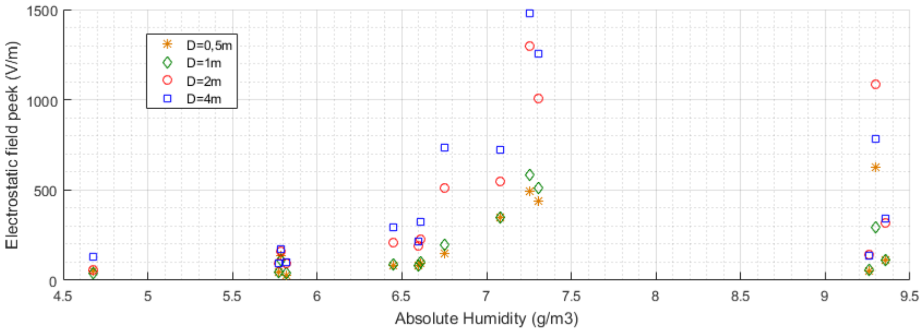

Fig. 20: Electric field strength dependent on ambient humidity and mass flux (release nozzle diameter, respectively)

Background Oriented Schlieren (BOS). So besides the actual objective to determine discharge coefficients for the cryogenic hydrogen, the experiments will provide indications on whether the quite simple BOS technology might be used for far field observation with natural backgrounds, like those encountered at hydrogen fueling stations, for instance.

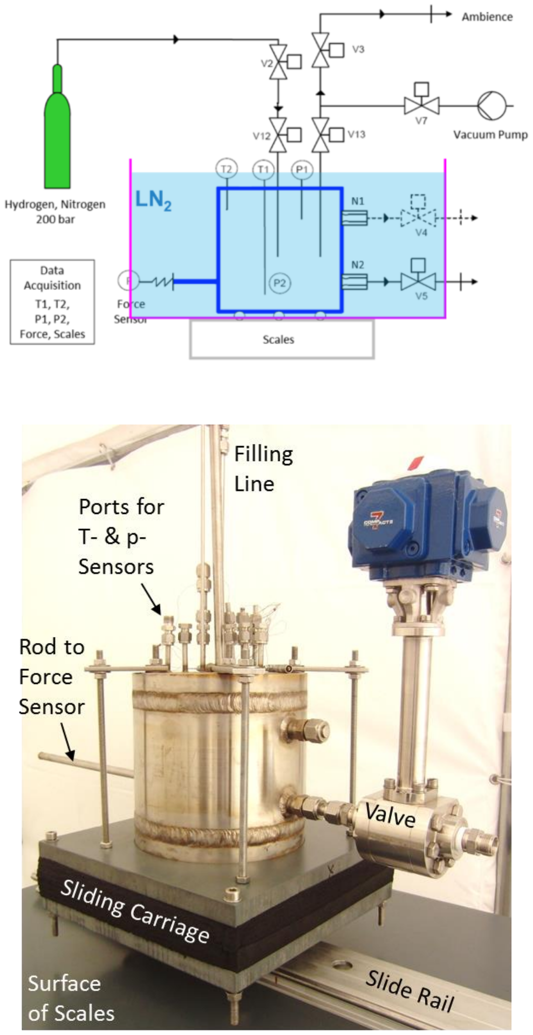

Fig. 22: DISCHA facility and experimental set-up for 80K hydrogen discharge releases

The minimum temperature which might be achieved by liquid nitrogen cooling of the DISCHA facility is 80 K. Therefore cold, but only single phase gaseous hydrogen releases might be studied with DISCHA. Assessing the effects of the liquid-gas interface during a blow-down and the determination of corresponding discharge coefficients requires a specially prepared cryo-vessel (see Fig. 23). The design of this experimental set-up has been finished, the construction of the special flange is on the way.

Fig. 23: Experimental set-up CRYO-VESSEL for two phase cryogenic hydrogen blow-downs

For the investigation of flame acceleration (FA) and deflagration-to-detonation (DDT) phenomena at cryogenic temperatures the special combustion tube CRYOTUBE with internal LN2 cooling has been designed and built (see Fig. 24).

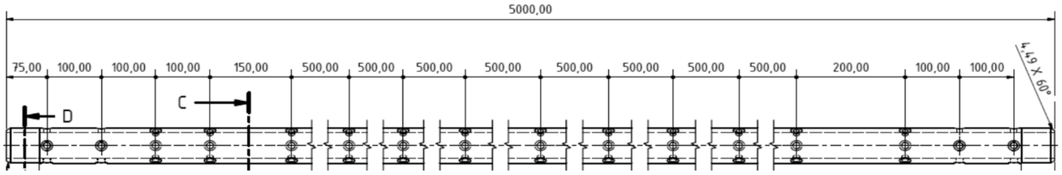

Fig. 24: LN2 cooled combustion tube CRYOTUBE with measurement ports

Results for the discharge, two phase blow-down and the cryogenic combustion characteristics are expected within the year 2019.

Catalytic Cleaning of High Pressure Hydrogen

As part of a cooperation with the Instituto Technico Buenos Aires, Argentina (ITBA) a catalytic cleaning process for high pressure electrolyzers has been investigated with a special experimental set up (see Fig. 25).

Several modifications for the feed gas arrangement have been used to achieve highest pressure in the experiments. Design criteria were derived by testing a few variants of the catalytic tube reactors (see Fig. 26), which were all equipped with the same small (about 4 mm in diameter) Pd-coated ceramic spheres, used as catalytic elements (see Fig. 27).

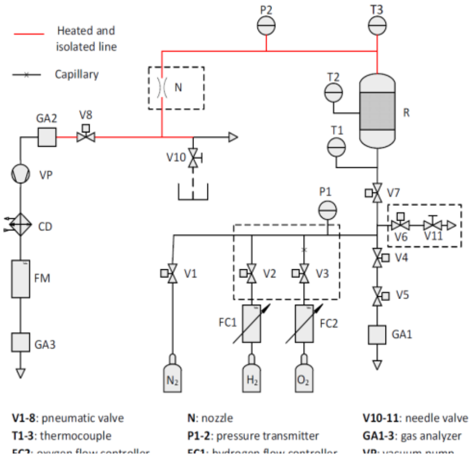

Fig. 25: PID of the experimental set-up for the catalytic cleaning of high pressure hydrogen

Fig. 26: Tested catalytic reactor variants

Fig. 27: Disassembled reactor variant R1 (with 1= spacer grid system, 2=exhaust thermocouple, 3=catalytic pellets,4=reactor shell, 5 = feed thermocouple, 6= reactor thermocouple)

Several test series were carried out with different set up configurations, most of them of them controlled with a stepwise increase of the oxygen contaminant concentration. The main results are the dry hydrogen or oxygen concentrations at the reactor outlet and the efficiency defined by comparing these values to the corresponding inlet concentrations.

The efficiencies of the catalytic reactors show inversely proportional correlation to the residence time of the gas mixture in the reactors. Feed concentration and reactor temperature show linear correlations. This outcome may be used to estimate the feed concentration by measuring the reactor temperature, being this a simple alternative instead of using gas analyzers.

The test performed with oxygen rich concentration shows a similar behavior when compared to hydrogen rich mixtures. However a feed concentration threshold in order the catalytic process to start is observed and further tests should be performed to better assess its behavior.

Pressure is found to have a positive impact on the efficiency of the process for the pressure range of 10 to 70 bar with a 10% efficiency increase. Tests performed at higher pressures (~ 90 bar) show a strange behavior leading to the assumption that steam adsorption is being developed by the catalytic material. Taking into account the aforementioned plus the fact that test pressure was limited due to needle valve choking events, modifications to the experimental set up are proposed in order to conduct tests at higher pressures.

The reactor variant R2 (tests 36, 37 and 57 in Fig. 28) turned out to be one with best performance under the conditions which are relevant for the prototypical alkaline high pressure electrolyser developed at ITBA. The reactor will be integrated there in 2019.

Overall, the catalytic cleaning process tested showed good performance and behavior understanding for the tests conducted at pressures below 70 bar. On the other hand, the working pressure limitation of the experimental set up prevented to fully understand the behavior of the process at pressures above 90 bar and further modifications to the facility should be conducted.

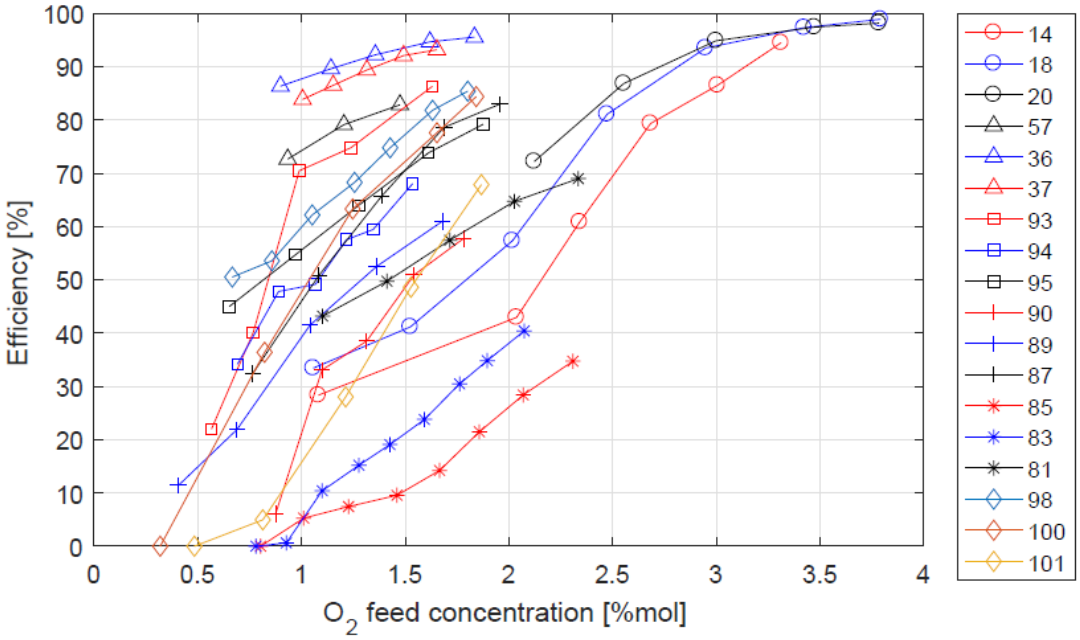

Fig. 28: Efficiency as a function of feed oxygen concentration