Hyindoor

Pre normative research
on the indoor use of fuel cells and hydrogen systems

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Indoor use of hydrogen, knowledge gaps and priorities for the improvement of current standards on hydrogen, a presentation of Hyindoor Europeen Project

B.L'Hostis, S. Ruban, G. Bernard-Michel, A. Kotchourko, S. Brennan, R. Dey
P. Hooker, D. Baraldi, A. Venetsanos, J. Der Kinderen

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Agenda:

- Introduction
- Hyindoor presentation
- Safety strategies and boundary of scenarios that needs to be assessed
- Identified questions and knowledge gaps
- Scientific approach and expected outputs
- Conclusion

Introduction

Use of H_2 in confined environments requires detailed assessments of hazards and associated risks, including potential risk reduction measures. The release of H_2 can potentially lead to its accumulation and the formation of a flammable H_2-air mixture.

Safety design guidelines and engineering tools need to be developed for use with specific safety strategies for various HFC applications.

Closing knowledge gaps is critical to this effort in several areas:

1. H_2 release conditions and potential for accumulation,
2. Venting of deflagration of localized or homogeneous mixture,
3. Indoor fire regimes (e.g., well-ventilated and under-ventilated fire, self-extinction of flame, external flames, etc.).

Hyindoor is a pre-normative research on safe indoor use of fuel cells and hydrogen systems

HyIndoor is a three year project started in 2012 and gathers key players in the field comprising :

- Industry (AL,HFCS),
- Research organisations (CEA, KIT-G, HSL, JRC, NCSRD)
- Academia (UU),

and an actor in RCS development (CCS Global Group).

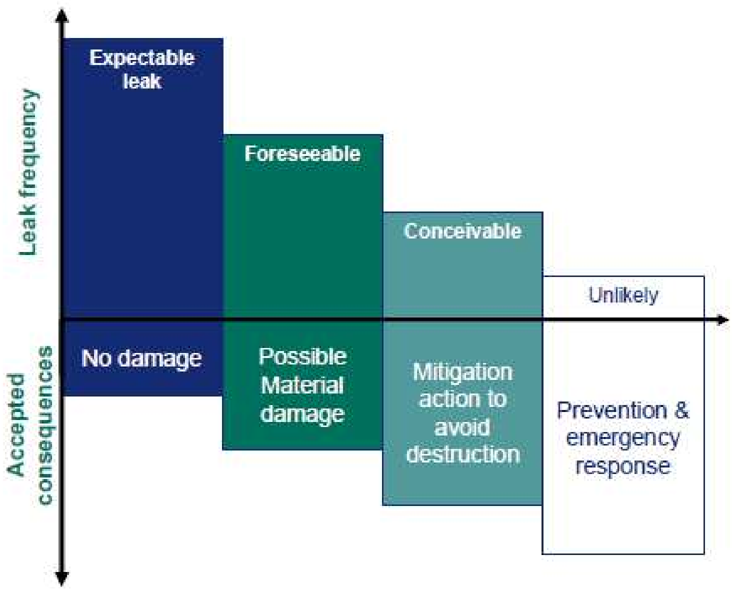
It aims to provide scientific and engineering knowledge for the specification of cost-effective means to control hazards, and to develop state-of-the art guidelines

1-Safety strategies and boundary of scenarios that needs to be assessed

- **General safety approach and definition of safety objectives**

The proposed safety approach allows us to address all potential leaks of hydrogen by prevention or mitigation measures to achieve a pre-defined specified safety objective, defined in terms of acceptable consequences. These objectives are defined in function of the likelihood of each potential leak to be considered.

Figure 1: Safety objectives expressed as accepted consequences related to leak frequency



1-Safety strategies and boundary of scenarios that needs to be assessed

- **Safety strategy to achieve safety objectives**

The safety objectives are expressed in terms of technical / quantified objectives which allow designers to size mitigation measures.

These technical objectives are related to:

- limiting the concentrations,
- limiting the overpressures,
- limiting the thermal effects,

and increasing the structure resistance.

The last means is not studied in the HyIndoor project.

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Typical industrial configurations

The following typical industrial HFC applications have been identified and studied within the project:

- Forklift vehicle operation
- Operation of a fuel cell in a room where other activities are performed (e.g. providing back-up power to a data centre)
- Storage of hydrogen in a dedicated room (supplying hydrogen to a fuel cell)

Photo credit: HyGEAR, Air Liquide

- Storage of hydrogen and distribution to a fuel cell in a cabinet or a larger container (located outdoors or indoors)
- Use of a portable fuel cell generator with its hydrogen supply indoors

2-Identified questions and knowledge gaps

For choosing the optimum safety strategy and designing/sizing the corresponding safety means, we need to close a number of knowledge gaps and answer a number of questions:

1. Limiting the concentration
2. Limiting thickness of the flammable layer
3. Limiting overpressure
4. Limiting the flame extension outside the enclosure

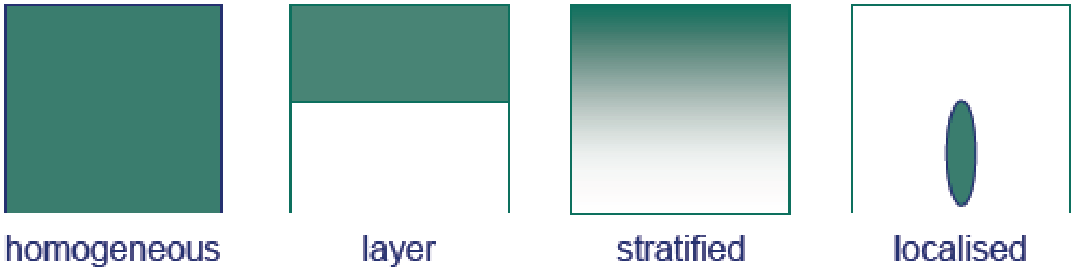
2-1 Limiting the concentration

- ***Assuming only natural ventilation is used***

For a given leak mass flow-rate and vent openings configuration:

- What are the limits on the release conditions (velocity, direction, distance to ceiling and walls…) that determine the different dispersion regimes?

Figure 2: H2 dispersion regimes in a naturally ventilated enclosure



- What is the influence of the leak height on the maximum concentration?

2-1 Limiting the concentration

- **For sizing the vent, how to consider the influence of:**

  - Vent design (grids, wind or weather protecting cover),
  - Wind conditions
  - Obstacles in the enclosure

- **What are the limits of application of the answers to the above questions with regard to the characteristics of the enclosure?**
  - Size
  - Aspect ratio
  - Location and direction of release

2-1 Limiting the concentration

- **Assuming use of H2 sensor and isolation and natural ventilation?**

For a given leak mass flow-rate, sensors have to be located on the ceiling:
- How much time do we have to detect and isolate the leak source before exceeding a specified maximum allowable concentration?
- What sensor technology is the most effective for that purpose?

- ***Assuming use of mechanical ventilation***

- How to size and locate mechanical ventilation to avoid exceeding a specified concentration in the conditions leading to the highest maximum concentration?

2-2 Limiting thickness of the flammable layer

- Assuming use of vents

- What are the vent location and size to limit the thickness of the flammable layer?

2-3 Limiting overpressure

- Assuming use of vents

- For a given hydrogen dispersion regime, how to size and locate the vents to avoid exceeding a specified overpressure inside or outside enclosure, based on the following parameters?

  - Displacement regime: size of layer and maximum concentration,
  - Stratified regime: maximum concentration and gradient,
  - Fully mixed regime: concentration
  - Combustible mixture in the dilution volume of the leak: combustible mass and release conditions,

2-3 Limiting overpressure

For a given leak size, what is the dispersion regime that requires the largest vents to achieve the overpressure limit?

For sizing the vent, how to consider the influence of:

- Equipment volume and piping size and spacing
- Vent grids
- Pre-existing turbulence brought by the leak itself (jet release)
- Pre-existing turbulence brought by mechanical ventilation
- Inertia of the vent

2-4 Limiting the flame extension outside the enclosure

- What factors influence the extension of the flame through the vent generated by the combustion of un-burnt mixture outside the enclosure?

3- Scientific approach and expected outputs

- Analysis and comparison of existing simple models and CFD models with past experiments

- Providing new experimental results

- Development and validation of new analytical and CFD models.

3-1 Dispersion of hydrogen in a confined space

A number of simple models to predict hydrogen concentration following a leak in an enclosure have been described in literature.
It distinguished 3 main idealized configurations.

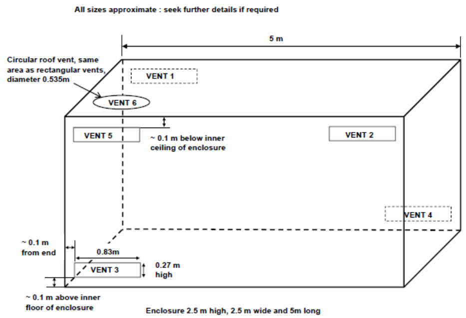
HyIndoor objectives are to:

- identify the conditions and limits of the different regimes that were described

- and to assess to what extend and how it will be necessary to take into account the following parameters in the sizing of the vents openings:

  ▫ Wind: will be investigated in HSL experimental programme

  Exp. set-up used: HSL «31,25m3 test facility



  ▫ Source momentum (sonic jet): will be investigated in CEA and HSL experiments

  ▫ Aspect ratio (elongated box, and very large enclosure, like the one we have in warehouse): will be investigated in CEA experiments

3-2 Deflagration of hydrogen in a confined space

Only a few simple models dedicated to hydrogen have been developed and validated yet to predict overpressure following a deflagration in a confined space: Molkov and Bauwens.

HyIndoor objectives are to continue to validate and improve these correlations for smaller and larger enclosures and propose guidelines to size vent openings to fulfill objective 2 or 3, taking into account real situations.

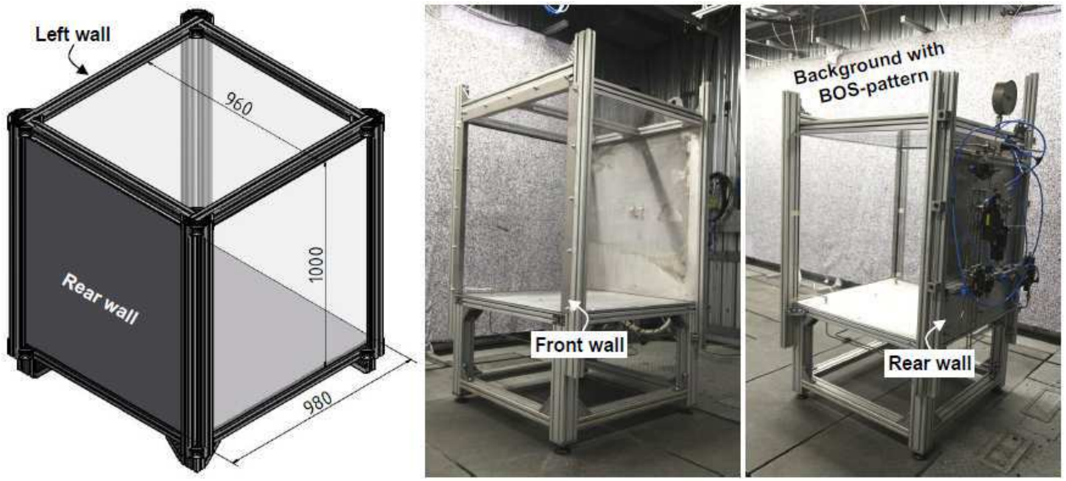
In addition, partners intend to develop a simple model to evaluate the maximum overpressure induced by a localized mixture deflagration, e.g. when the flammable volume is very limited compared to the volume of the enclosure volume and set the limits of applicability of such a model. This model will be validated against KIT experiments.

The project will also allow to experimentally validate the model for so-called pressure peaking effect proposed by Brennan et al.

3-2 Deflagration of hydrogen in a confined space

Expected improvement within HyIndoor will include:

- Scaling capabilities (enclosure volume from 0,01 m3 to 120 m3)
- Ability to predict maximum overpressure inside and extent of effects (flame /overpressure) outside enclosure
- Ability to predict adequately potential for flame acceleration depending on mixture composition and distribution, initial level of turbulence, vent parameters and obstacle configuration



Experimental set-up used: (0,94m 3) inside the 160 m3 test chamber

3-3 Well ventilated and under-ventilated fires indoor

Hydrogen non-premixed combustion in enclosure has not been specifically studied to the partners’ knowledge.

The goal is to quantify what the phenomena that might happen for a given leak rate, enclosure volume and vent(s) characteristics. It may confirm the defined safety objective (which did not consider this phenomena) or necessitate for instance to take risk of flame extinguishment and re-ignition into account in specific leak versus volume cases.

Different regimes need to be described and their limits defined:

- Well ventilated jet fire (complete combustion of hydrogen within the enclosure) or plume with similar associated effects
- Under-ventilated fire
- Self-extinguishment

KIT and HSL facilities described above will be reused to test fire phenomena:

Conclusions

The HyIndoor **pre-normative research** project identified and ranked knowledge gaps on hazards related to hydrogen behaviour in naturally ventilated enclosures. It is focused on **industrial needs to design inherently safer installations and will generate new knowledge about hydrogen accumulation** regimes, vented deflagrations, and hydrogen fires in confined space through complementarities and synergies of experimental, analytical and numerical studies.

The outcome of HyIndoor project will be **guidelines, engineering tools and recommendations for RCS improvements allowing the** development of safety strategies and practical engineering solutions that will comprehensively address all potential hydrogen leaks and associated hazards for any hydrogen and/or fuel cell system, in order to provide expected level of life safety. and property protection.

Thank you for your attention.

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