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Optimising Hydrogen Sensor Networks for Enhancing Safety in the Refuelling Station

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Introduction

Future Hydrogen Refuelling Stations (HRS) will be equipped with their own photovoltaic power system and electrolyser, placed in a container, for an independent local generation of green hydrogen. Focusing on public safety, there is a need for understanding the dynamics of hydrogen concentration in such an electrolyser unit. Specifically, it involves studying the behaviour of hydrogen concentration over time as it increases during release or hydrogen leak and decreases because of losses, i.e. the leak from the container to the surroundings.

Methods und Materials

An office container was used as a measuring cell with a network of 12 sensors distributed throughout the container. In this setup a hydrogen release scenario was performed on container size level – 4.66 m × 2.21 m × 2.54 m (length/width/height). The hydrogen sensors were placed at different positions inside. A 5.5 Vol-% hydrogen in nitrogen mixture, i.e. the MXC-mixture[1], was emitted through a quarter inch tube into the container. Ambient temperature and humidity were measured. Hydrogen was released into the container to simulate a leak, and the sensors' responses were recorded.

The initial phase of a test run involved a controlled release of hydrogen gas into the container. Even reasonably moderate gas flow (typically 2 L/h) rates could not completely avoid some forced convection. Sensor signal data was recorded at 3.3 Hz. The release was continued for five to ten minutes aiming at the analysis of the volume fraction-time-history recorded.

When the hydrogen release was stopped, natural dispersion and dilution within the container could take place. The sensor continued to record hydrogen levels as the concentration declined over time for some hours. This loss pattern followed an exponential trend, enabling the calculation of the decay constant τ, which is crucial for assessing the rate at which hydrogen volume fraction decreases in a not perfectly enclosed space. The results of these analyses were plotted to visualise both the volume fraction increase and decay.

Results

Real scale tests resulted in detailed concentration-time-history data sets for a well-controlled setting, revealing the release is best described by a linear relationship while the loss is best described by an exponential function. Thus, two key parameters could be determined:

β / Vol-% h^{-1}: The rate of increase in hydrogen concentration during the injection phase.

τ / h: The loss constant representing the rate of exponential decrease in hydrogen concentration.

The two corresponding equations are:

$$\phi_{H2}(t) = \boldsymbol{\beta}\, t + a \qquad (1)$$

$$\phi_{H2}(t) = \phi_{H2-CRM}\; e^{\left(-\frac{t}{\tau}\right)} \qquad (2)$$

where φ_{H2} is the hydrogen volume fraction / Vol-%, a is the axis intercept, $\varphi_{H2\text{-}CRM}$ is the volume fraction of the used certified reference material in Vol-% (CRYSTAL-Gemisch with 5.55 Vol-% ± 0.11 Vol-% Hydrogen in Nitrogen, AirLiquide), *t* is the time in min and τ is the loss constant / unit time.

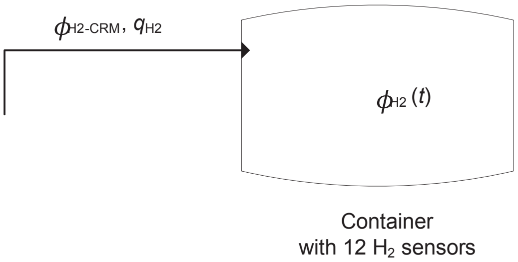

Figure 1: Pipe plan for detection of released hydrogen.

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[1] MXC = maximum flammable gas content for which a mixture of the flammable gas *i* in an inert gas [2]

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As hydrogen being highly flammable its concentration vs. time constantly needs to be monitored. Counter measures can be taken long before the Lower Explosive Limit (LEL) [1] could ever be reached.

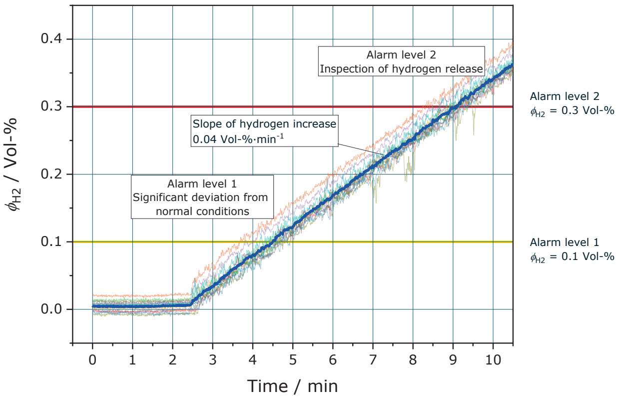


Figure 2: Time series of observed hydrogen data. The slope is showing the mean hydrogen increase of $\beta = 0.04$ Vol-% min-1 ± 0.015 Vol-% min$^{-1.}$

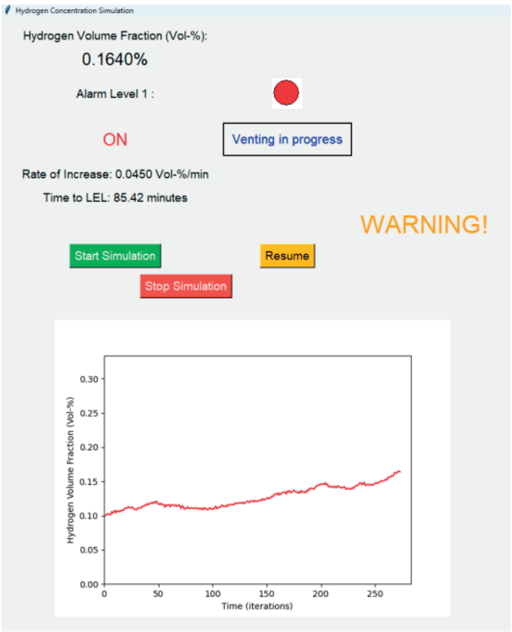
The values of β and τ were calculated for multiple datasets, enabling comparison across different experimental runs, ***Table 1***.

Table 1: τ and β values calculated for the individual sensors in a non homogenized test run (no external air mixing source).

Sensor ID	τ / h	β / Vol-% h^{-1}
091594	7.84	2.70
091595	8.47	2.60
091596	7.36	2.81
091597	6.78	3.01
091598	8.06	2.82
091599	NAN	NAN
091600	8.34	2.79
091601	7.53	2.79
091602	8.44	2.63
091603	8.16	2.74
091604	6.29	3.09
091605	6.91	2.85

Discussion

These findings provide a basis for estimating hydrogen behaviour in confined spaces, underscoring the importance of understanding both the accumulation rate and dissipation dynamics for safety considerations in hydrogen storage and refuelling environment, especially in an electrolyser unit. Note that the sensor 091599 did not respond due toas expected. Therefore, the sensor is skipped in this analysis. This gives an opportunity for a computer assisted safety monitoring. The AI could then draw operator's attention to take appropriate safety measures aiming at the protection of people and the plant, respectively. To represent the process of informed decision making, a process monitoring system with appropriate alarm levels was developed using python script as shown in the figure 3. The first alarm level is a visual alarm represented with a red led and the level 2 alarm is an audio one with a warning message.


Hydrogen Concentration Simulation

Hydrogen Volume Fraction (Vol-%):
0.1640%

Alarm Level 1 : ●

ON

Venting in progress

Rate of Increase: 0.0450 Vol-%/min

Time to LEL: 85.42 minutes

WARNING!

Figure 3: The GUI of the process monitoring system with integrated alarm function.

The results demonstrate that even small, controlled hydrogen releases as a leakage can lead to an explosive hydrogen mixture. Adequate leak detection, ventilation and evacuation planning is essential. Predicting the dissipation of hydrogen to safe levels is relevant for assessing time-to-safety after a release event, reinforces the need for safety protocols in confined spaces to avoid hydrogen reaching hazardous levels.

References

[1] F.Ganci , A. Carpignano , N. Mattei , M. N.Carcassi *Hydrogen release and atmospheric dispersion: Experimental studies and comparison with parametric simulations,* 2011

[2] V.Schröder,https://opus4.kobv.de/opus4-bam/files/41830/Schroeder++Calculation+of+Flammability+Limits.pdf

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