DOI 10.5162/SMSI2025/C6.2

# Hydrogen Safety - Dealing with Closed Spaces

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**Summary:**
Hydrogen is under discussion as a potentially clean energy source, but its safe usage and handling in enclosed environments remains a critical challenge due to the properties of hydrogen. This work focuses on detecting and monitoring hydrogen concentration in closed spaces to improve safety by developing a sensor network-based leak detection system to prevent of the accumulation of hazardous mixtures. Furthermore, the study details the implementation of a hydrogen sensor network within a container, analysing sensor placement, data collection, and safety improvements. The findings contribute to better risk assessment and enhanced safety protocols in hydrogen storage and usage facilities.

**Keywords:** Hydrogen, Safety, Sensor network, Refuelling Station, Measurement Uncertainty

## Background

In recent years, strategies for using hydrogen for decarbonisation have been proposed. An interesting example is the National Hydrogen Strategy of Germany [1]. These strategies also include increased research into the safety aspects of hydrogen to ensure public acceptance and reduce the risk of financial and human losses due to unforeseen hazards. This paper deals with the analysis of hydrogen release dynamics in an enclosed space and the use of sensor technology to detect a leak at an early stage and implement safety measures before potentially hazardous conditions are reached.

## Introduction

Safe handling of hydrogen in enclosed spaces presents challenges due to its low molecular weight, high diffusivity, and wide flammability range [2]. A common practice in Europe is using containers to divide the hydrogen usage area with containers. As these areas are smaller and closed, a sensor network to find leaks is necessary [3]. Knowing the influence of ventilation on the dynamics of hydrogen in closed areas is essential to determine the placement of the sensors.

Figure 1 shows the flammability diagram for $H_2$-AIR-$N_2$ mixtures, which provides a critical framework for assessing hydrogen-related explosion hazards in enclosed environments. It graphically defines the flammable region where combustion can occur based on the volumetric composition of hydrogen ($H_2$), Air (Oxidizers in air), and nitrogen ($N_2$). The area is bounded by the lower flammability limit (LFL) and upper flammability limit (UFL), outside of which ignition is not sustainable [4].

In closed spaces, inert gases like nitrogen significantly influence flammability by suppressing flame propagation and altering the minimum ignition energy requirements. In less-ventilated areas, hydrogen accumulation can create flammable mixtures.

Understanding the flammability limits in confined spaces is essential for designing effective sensor networks, implementing ventilation strategies, and ensuring safe hydrogen storage and handling in industrial and energy applications.

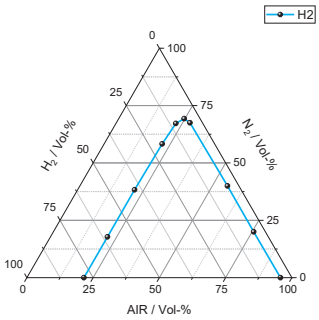



*Fig 1: The flammability diagram for $H_2$-AIR-$N_2$ mixture.*

The main goal of this experiment is to find the hydrogen dynamics in the container, exemplary for a hydrogen electrolyser unit. The time to disperse the hydrogen after a leak is determined to make a safety protocol.

## Experimental Setup and Sensor Network

The experiment was conducted in different phases. Initially, a database of commercially

available sensors developed during the project H2-Sense [5] was updated to a Microsoft -Access based system. The sensor XEN-5320 from Xensor was selected for its fast response, making it suitable for leak detection.

The sensors are distributed across the container at different levels to determine the hydrogen volume fraction. As soon as the controlled release of hydrogen is stopped, the escape of the hydrogen in the containment is determined without external airflow. This will help continuously monitor the hydrogen concentration and help find the formation of potential explosion mixtures.

The two corresponding equations are:

$$\phi_{H2}(t) = \beta \cdot t + a \quad (1)$$

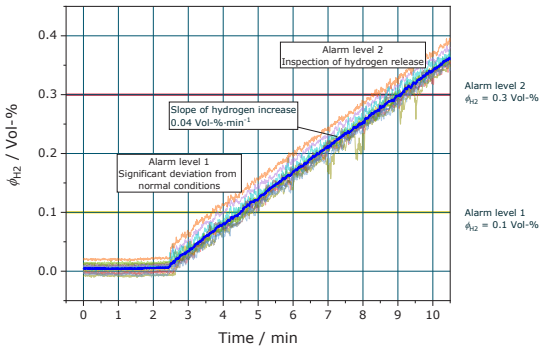
$$\phi_{H2}(t) = \phi_{H2-CRM} \cdot e^{-t \cdot \tau} \quad (2)$$

where $\beta$ is the rate of increase of hydrogen concentration, $\varphi_{H2}$ is the hydrogen concentration in Vol-%, a is the axis intercept, $\phi_{H2-CRM}$ is the volume fraction of the used certified reference material in Vol-% (“MXC-Mixture” with 5.55 Vol-% ± 0.11 Vol-% Hydrogen in Nitrogen, AirLiquide, i.e. this mixture can be mixed with any amount of air and will never form an explosive mixture), $t$ is the time in min and $\tau$ is the loss constant / min.

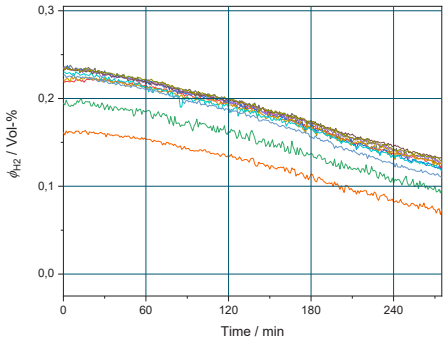
## Results

In this study, uncertainty was evaluated using the GUM (Guide to the Expression of Uncertainty in Measurement) framework, incorporating both Type A (statistical) and Type B (systematic) uncertainties. The expanded uncertainty for hydrogen concentration ($\varphi_{H_2}$) was determined to be 0.017% at a 95% confidence level, indicating the precision of the sensor measurements. Contributing factors include uncertainties in container volume ($V_{con}$ = 26.16 m³ ± 0.02 m³), gas exchange rate ($n$ = 0.72 h⁻¹ ± 0.05 h⁻¹), and retention time ($\tau$ = 5020 s ± 370 s). The discrepancy between theoretical and measured concentrations ($\Delta\varphi_{H_2}$ = -0.121% ± 0.080%) highlights the impact of sensor response variations and environmental conditions. Characterisation of these uncertainties ensures reliable hydrogen safety monitoring in closed spaces and supports the development of more robust detection strategies.

Figure 3 (a) shows the increase in the concentration during the hydrogen release and various alarm levels. Figure 3 (b) shows the distribution of hydrogen within the container by natural dispersion. The sensors closer to the windows show lesser concentrations, showing faster dissipation near the windows even when closed. The accumulation of hydrogen is first seen at the top of the container, with maximum accumulation near the leak source.




*(a)*




*(b)*

*Fig 3: (a) shows the concentration increase in the container during the controlled release of hydrogen. (b) Shows the dispersion of hydrogen as detected by different sensors without any external ventilation*

The findings validate the effectiveness of a sensor network for real-time leak detection and provide critical insights for optimising sensor placement and improving hydrogen safety strategies in closed environments.

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