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Hydrogen leak detection: monitoring and control methodologies

Morena Vitale[1], Micaela Demichela[1], Antonello Barresi[1]

(1) Department of Applied Science and Technology, Politecnico di Torino, morena.vitale@polito.it

A promising gas for reducing environmental pollution and the use of fossil fuels is hydrogen. Compared to hydrocarbons, hydrogen offers the advantage of generating only water as combustion product. Hydrogen has a low density (0.0899 kg/m^3), making it extremely light. Furthermore, it has a wide flammability range, between 4% and 75%, and a relatively low minimum ignition energy of 0.017 mJ. Consequently, in the event of a leak, there is a risk that the hydrogen forms flammable mixtures with air, which can easily trigger jet fires (Elaoud et al., 2009).

Furthermore, due to the extremely small size of hydrogen molecules, this gas can penetrate materials, compromising their microscopic and macroscopic tensile strength, fatigue strength and fracture toughness (Dwivedi and Vishwakarma, 2018). This phenomenon is known as hydrogen embrittlement (HE), a complex phenomenon involving several mechanisms including the physical and chemical absorption and hydrogen dissolution.

Numerous studies have focused on the analysis of hydrogen losses to outline a concentration distribution model in time and space, necessary to calculate a safety distance. The aforementioned parameter plays a fundamental role in ensuring safety in the vicinity of hydrogen infrastructure. This takes on relevance in the context of the design of plants and distribution networks intended for a more widespread use of the gas, underlining the importance of adopting rigorous safety criteria to protect both people and surrounding structures.

Additional research, performed at laboratory level with different methodologies, was performed to simulate the behavior of hydrogen to develop descriptive equations, especially in situations of leakage from tanks or pipes. Monitoring hydrogen leaks is important to ensure safety in the process industry, considering the ageing of infrastructure and natural events that can increase the frequency of these leaks. Nowadays, however, there is a lack of research that specifically addresses the detection of hydrogen leaks on a plant scale.

This monitoring can be carried out using different platforms capable of acquiring data, such as photographs and/or videos, from different altitudes, thus providing a diversified spatio-temporal resolution (Pillosu, 2020). Drones, also known as unmanned aerial vehicles (UAVs), emerge as the most versatile and flexible platforms, as they are controlled by an operator on the ground, who can pre-set the flight plan or change direction, altitude, and speed during the flight itself. These platforms cover smaller areas, which results in data of greater precision and resolution. The use of drones for monitoring requires the installation of a specific device, known as sensor, designed to detect released gases or small fires that are difficult to detect. The specified tool allows to capture photos and/or videos at safe distances. This methodology is particularly suitable in the presence of flammable or corrosive substances, which could compromise or cause malfunctions in the equipment. Druart et al. (2021) used a drone-mounted infrared camera to detect methane leaks from a storage tank. The test was conducted at three different flight heights: 80 m, 40 m and 20 m, with gas losses of 200 g/s, 10 g/s and 1 g/s respectively. The study showed that even at an altitude of 80 m also the smallest methane leak can be clearly detected. This form of monitoring has advantages in terms of the speed of real-time data acquisition and the ability to locate gas leaks in a totally safe way.

The use of drones equipped with cameras represents an effective solution to address the problem of hydrogen leaks. The most widespread technologies on the market for identifying the presence of combustibles in the air include infrared sensors and catalytic bed sensors. However, hydrogen is not capable of absorbing infrared radiation like hydrocarbons. On the other hand, catalytic bed sensors do not allow detection at safe distances. Two methods are proposed to address the proposed problem:

- The Schlieren method for gas detection is an optical technique that exploits density variations in a transparent medium, offering the possibility of visualizing and recording gas flows. Density variations within the gas cause light rays to bend, creating patterns known as Schlieren lines or density shadows. By using a sensing system, such as a high-sensitivity camera that can be placed on the drone, changes in light intensity in density shadows can be captured. The resulting images allow to highlight variations in gas density, making visible leaks or flows allowing real-time monitoring (Hargather and Settles, 2012)
- Hydrogen, thanks to its low minimum ignition energy value and high heat of combustion, is capable of easily generating jet fire once released, producing a significant amount of heat. These can be easily detected using a thermal camera installed on a drone, allowing real-time monitoring of hydrogen leaks.

Therefore, the primary objective of this research is to formulate advanced methodologies to implement an effective monitoring and control system to detect any hydrogen leaks within industrial process plants. The study contributes to the POC Multi-risk analysis of energy and process infrastructures.

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