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Hydrogen-Explosion Risk Reduction by Hazardous Area

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Paper logo

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Introduction

Hydrogen production is rising in popularity globally due to the increasing demand for clean energy. Operating companies are going to focus more and more on hydrogen projects in future. However, to be accepted widely by society, hydrogen projects should be executed safely and cost-effectively. The biggest challenge is the lack of proper industry standards/guidance and experience available for mitigating hazards associated with hydrogen mainly when the equipment is located indoors in an existing building or congested modules. In both cases, explosion-safe design becomes a major consideration, and an adequate risk assessment becomes essential to comply with DSEAR or ATEX directive.

Hydrogen is a light gas with wide flammability range, even a very small release over time in a confined space can result in a build-up of hydrogen at the ceiling level or within the equipment enclosure leading to explosion risk. Whereas for an unconfined release in the open air, the gas is likely to dissipate quickly thereby reducing explosion risk and, in most instances, leading to non-hazardous classification. Therefore, a proper classification is required to ensure that an optimum and safe design is selected. Particularly when executing fast-track projects, there could be potential cost and delay associated with the procurement of ATEX-rated equipment and in some instances, certain equipment may not be readily available for a hydrogen environment.

This paper discusses various approaches including risk-based approach to area classification when hydrogen is being utilised. It also highlights, key difference between area classification for hydrogen and other flammable gases/vapours and challenges associated with electrical classification of hydrogen especially when hydrogen is being processed or stored indoors. The paper succinctly discusses various codes, standards and guidelines that are used for electrical classification of facilities processing or storing hydrogen. With early detection of hydrogen leaks and how gas detection system can be interlocked with HVAC system to benefit the overall area classification design for explosion prevention. Finally, the paper presents a case study to demonstrate on how explosion hazards can be reduced or mitigated or prevented altogether by performing area classification study and by selecting appropriate electrical and mechanical equipment and thereby preventing the ignition of hydrogen-air mixtures or build-up of explosive mixtures by provision of adequate ventilation.

ATEX Background and Legal Framework

The general safety requirements for evaluation of explosion risk and determination of hazardous zones are outlined in the European directive 1999/92/EC. This directive specifies requirements for prevention of and protection against explosions, assessment of explosion risks and requirements for classification of places where explosive atmospheres may occur. In the UK to implement the European ATEX Directives is through Dangerous Substances and Explosive Atmospheres Regulations (DSEAR). There are two UK-based codes which are generally recognised to be adequate for the purposes of Area Classification. These codes are essentially for the chemical and oil industries which handle large quantities of flammable gases, liquids and vapours. The first one is BS EN 60079-10:2021 and it is identical to IEC 60079-10-1:2020. The second code is one developed primarily for the petroleum industry, Model Code of Safe Practice, Part 15, 4th edition, referred to as "EI 15".

The Table 1 list industry standards where some guidance/reference to hydrogen are provided. Within in Europe, mainly IEC 60079-10-1:2020 are followed, in addition different countries have their own location regulations which are not listed in paper. Table 1 list different standards where reference is made to hydrogen and hazardous area requirements.

UK/Europe	**America/Canda**	**Asia**
BS EN 60079-10:2021 EI 15 *IEC 60079-10-1:2020*	NFPA 497 API-RP-505 NFPA 2: Hydrogen Technology Code CAN/BNQ 1784-000	Indian: OISD 113, IS-5571

Table 1 : List of Area Classification Related Code and Standard

Dangerous Properties of Hydrogen

Hydrogen, one of the lightest elements on earth, is colourless, odourless and highly combustible, thus posing serious risks of fire and explosion when a leak occurs. Hydrogen has a rapid diffusivity (3.8 times faster than natural gas), which means that when released, it dilutes quickly into a non-flammable concentration. Hydrogen rises 2 times faster than helium and 6 times faster than natural gas at a speed of almost 45 mph (20m/s). Therefore, unless a roof, a poorly ventilated room or some other structure contains the rising gas, the laws of physics prevent hydrogen from staying near a leak (or near people using hydrogen-fuelled equipment. To become a fire/explosion hazard, hydrogen must first be confined – but as the lightest element in the universe, confining hydrogen is very difficult, and these inherently safer properties can be taken into account when designing structures where hydrogen will be used.

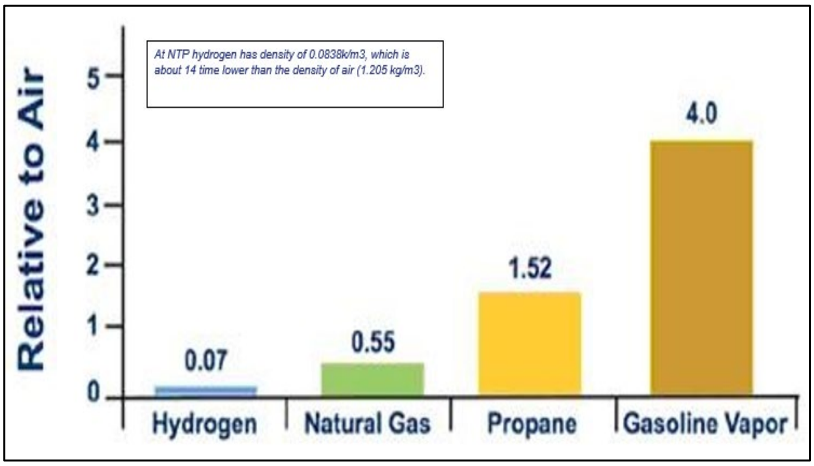

Figure 1: Density Comparison

In order for a hydrogen fire to occur, an adequate concentration of hydrogen, the presence of an ignition source and the right amount of oxidizer (like oxygen) must be present at the same time. Hydrogen has a wide flammability range (4- 74% in air, see Figure 2). The lower flammability limit (LFL) is the minimum amount of fuel that supports combustion, is usually the more important limit, since it will be reached. first in a continuous leakage.

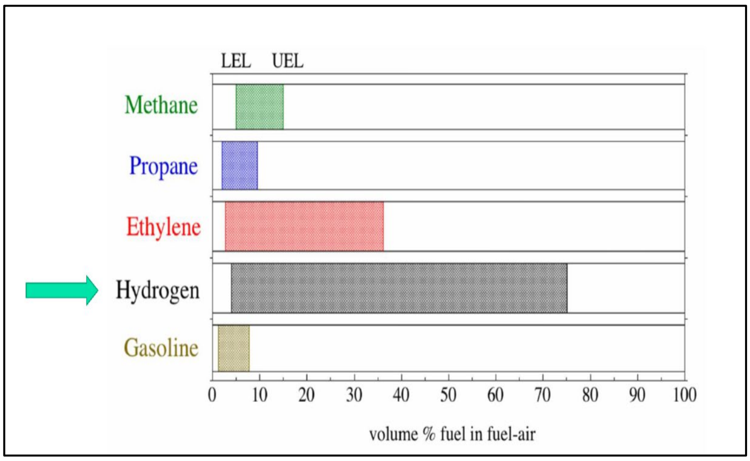

Figure 2: Flammability Limit Comparison

The minimum ignition energy required to ignite hydrogen (0.02mJ, see Figure 3) is very low. The minimum ignition energy of hydrogen in air is one of the lowest among known substances, and hydrogen-air mixtures can ignite with 1/10 the effort of igniting hydrocarbon-air mixtures. Because of this, any possible ignition source has to be scrutinized. However, at low concentrations (below 10%) the energy required to ignite hydrogen is high or similar to the energy required to ignite natural gas and gasoline in their respective flammability ranges, making hydrogen realistically more difficult to ignite near the lower flammability limit. On the other hand, if conditions exist where the hydrogen concentration increased toward the stoichiometric mixture of 30% hydrogen (in air), the ignition energy drops to about 1/15 of that required to ignite natural gas.

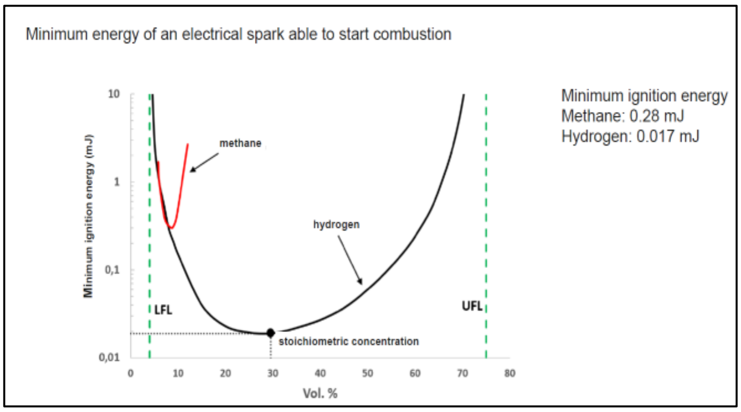

Figure 3: Vol % and Minimum Ignition Energy Comparison

Hydrogen burns extremely quickly compared to other flammable compounds, with a maximum speed of around 3.0 m/s (see Figure 4). Depending on the flammable conditions, pressure, and concentration of hydrogen, a mixture exposed to ignition sources may combust by either deflagration (subsonic combustion) or detonation (supersonic combustion, in confined spaces. The high burning velocity of hydrogen is an indication of its high explosive potential and the difficulty of confining or arresting hydrogen flames and explosions. The higher the burning velocity, the greater is the chance for a transition from deflagration to detonation (DDT). The detonability range is usually given to be 18 - 59 vol% of hydrogen concentration.

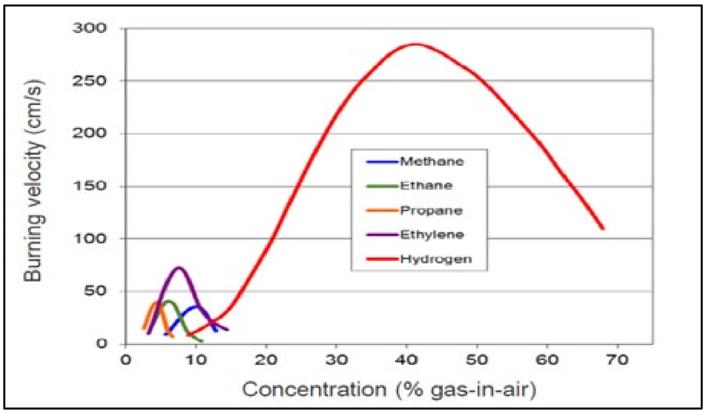

Figure 4: Burning Velocity -the of fuel type

Hazardous Area Classification

Hazardous areas are defined in DSEAR as "any place in which an explosive atmosphere may occur in quantities such as to require special precautions to protect the safety of workers". Area classification is a method of analysing and classifying the environment where explosive gas atmospheres may occur. The main purpose is to facilitate the proper selection and installation of apparatus to be used safely in that environment, taking into account the properties of the flammable materials that will be present. DSEAR specifically extends the original scope of this analysis, to take into account non-electrical sources of ignition, and mobile equipment that creates an ignition risk.

Hazardous areas are classified into zones based on an assessment of the frequency of the occurrence and duration of an explosive gas atmosphere. Various sources have tried to place time limits on to these zones, but none have been officially adopted. This is most common definition/frequency values as per UK HSE and other industry accepted standards are presented in Figure 6. A generic methodology for performing hazardous area classification is given in Figure 7.

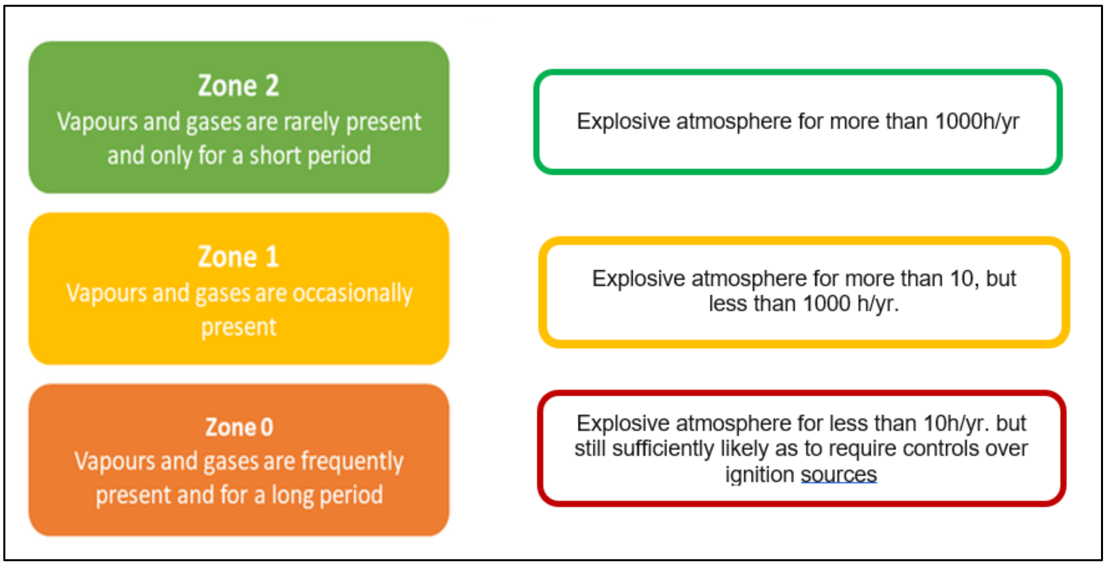

Figure 6 : HAC Zones

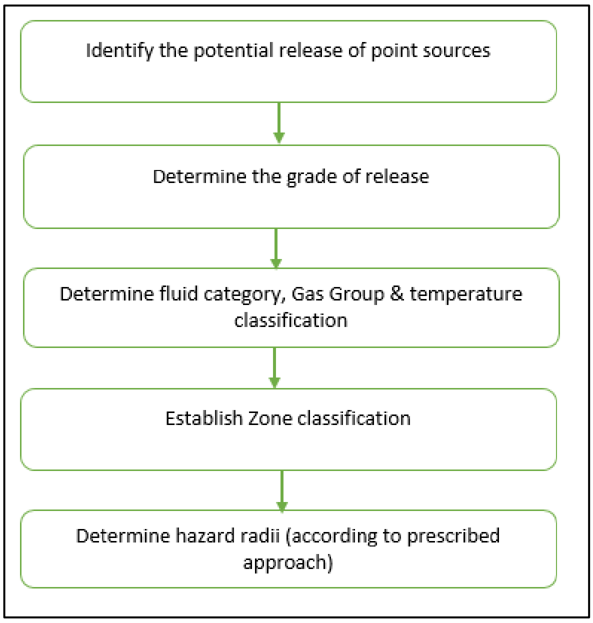

Figure 7 : HAC Methodology

Case Study

Facility Description & Challenges

The FEED (Front End Engineering Design) project was to design a Hydrogen Test Facility in England, UK that would provide a collaboration space for use with Client's customers accelerating bespoke product development and in application design verification by using customer relevant hardware and test conditions. The facility would also include dedicated test equipment for Quality release testing of manufactured components (CCM) and MEA product.

The Test Stand capability was specified by the Client to support diagnostic tests, accelerated test protocols (including cold start), online monitoring of lifetime metrics (electrochemical) and customer specific load/drive cycles.

The key equipment required by the Client to fulfil these objectives comprises four off Single Cell Test Stands for testing individual cells between 5 and 50cm2 up to 0.5 kW output, and three off larger Short Stack Test Stands for testing between 50 and 30 stacked cells, between 150 and 300 cm2 up to 12 kW output.

The Test Stands were vendor proprietary items and had already been purchased by the Client. The facility would serve the following:

- 4 off Single Cell Test Stands
- 3 off Short Cell Test Stands

The Test stands were stand-alone items of equipment. They were provided with an interface to control and manage the operation of the test Stands.

The following utilities were provided to the Test Stands: Hydrogen, oxygen, nitrogen, compressed air, Ultra-Pure Water and Chilled water. They also had three types of exhaust ventilation (Fuel ventilation, Oxidant Ventilation and Local Extract Ventilation). The three exhausts were designed to be kept separate and were required to have the necessary drainage connections to deal with the moisture that will condense as the exhaust is cooled.

The areas/rooms associated with Hydrogen Test Facility project were proposed at 12 m level in an existing building. Therefore, would fall within the remit of local building regulations. According to existing fire safety strategy the fire safety aspects of this existing building were designed using guidance provided in Approved Document B through which compliance with local building regulations was demonstrated. Therefore, rooms that were required to be constructed or utilised for Hydrogen Technology Test Facility would need to meet the requirements of Approved Document B.

Input Data

The area classification for test stand room was carried out in accordance with BS EN 60079-10-1. The H_2 feed line operating at 7.5barg and 50 ^oC were selected as the typical release point within the test stand room. The secondary release source considered were valve, flanges etc and the hole size of 0.564 mm was selected based on piping and valve since (i.e. Hole area, S=0.25mm2 from BS EN 600079-10-1, Table B.1). There was no primary release source within the room, all vents were located outside at a safe location. For this study DNV PHAST 8.6. was utilised for calculating the H_2 discharge flow rate within the test stand room for the secondary release sources.

Ventilation Study

A ventilation study was commissioned (as per BS EN-670079-10-1) to determine the degree of dilution within the test stand room and also to check if the existing HVAC which provided the 2ACH (air change per hour) was sufficient to keep “Zone 2” environment with this room. The ventilation study results showed that with 2 ACH, the degree of dilution within the room was “Low” (i.e., there was significant concentration whilst release was in progress and/or significant persistence of an explosive gas atmosphere after the release had stopped) and that would have led to “Zone 1” environment. To avoid the “Zone 1” classification, the air changes rate was increased to 6 ACH. Based on this, the room dilution was estimated to be medium and leading to Zone 2 classification within the test room. The ventilation results are presented in Figure 8 and 9. 6 ACH was selected as design case to provide sufficient air movement to dilute a hydrogen release and sufficient air exchange to ensure the adequate ventilation was provided within the test room.

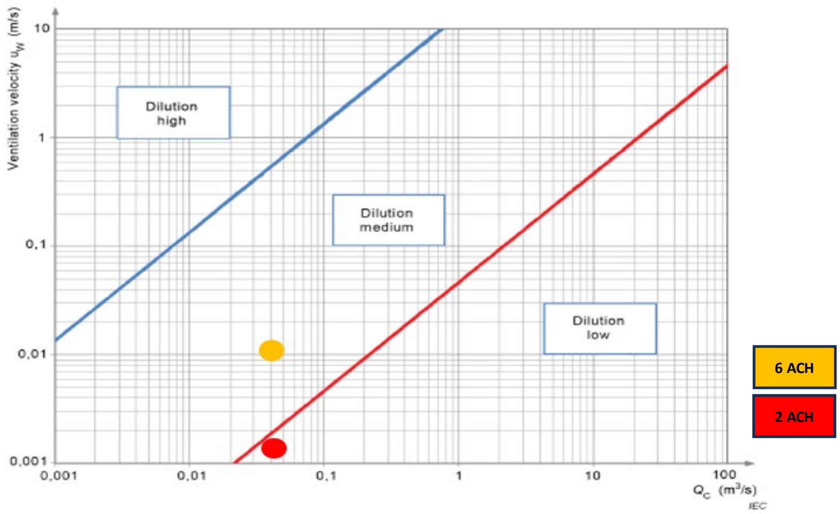

Figure C.1 – Chart for assessing the degree of dilution

Figure 8 Chart for Assessing the Degree of Dilution

Table D.1 – Zones for grade of release and effectiveness of ventilation

Grade of release	Effectiveness of Ventilation						
	High Dilution			Medium Dilution			Low Dilution
	Availability of ventilation						
	Good	Fair	Poor	Good	Fair	Poor	Good, fair or poor
Continuous	Non-hazardous (Zone 0 NE)[a]	Zone 2 (Zone 0 NE)[a]	Zone 1 (Zone 0 NE)[a]	Zone 0	Zone 0 + Zone 2[c]	Zone 0 + Zone 1	Zone 0
Primary	Non-hazardous (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or zone 0[d]
Secondary[b]	Non-hazardous (Zone 2 NE)[a]	Non-hazardous (Zone 2 NE)[a]	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 and even Zone 0[d]

[a] Zone 0 NE, 1 NE or 2 NE indicates a theoretical zone which would be of negligible extent under normal conditions.

[b] The Zone 2 area created by a secondary grade of release may exceed that attributable to a primary or continuous grade of release; in this case, the greater distance should be taken.

[c] Zone 1 is not needed here. I.e. small Zone 0 is in the area where the release is not controlled by the ventilation and larger Zone 2 for when ventilation fails.

[d] Will be Zone 0 if the ventilation is so weak and the release is such that in practice an explosive gas atmosphere exists virtually continuously (i.e. approaching a 'no ventilation' condition).

'+' signifies 'surrounded by'.

Availability of ventilation in naturally ventilated enclosed spaces is commonly not considered as good.

Figure 9: Zone for grade of release and effectiveness of ventilation.

HVAC and Gas Detection

The option to link the HVAC unit with gas detection to provide air changes to a value higher than 6 ACH was also explored as part of this study. However, the calculations results showed that to achieve this, a bigger Air Handling Unit (AHU) unit was needed. The implementation of this solution required larger space, cost and project time delays. Due to these challenges the option for linking the HVAC with gas detection was not taken forward. However, the test stand room was provided with gas detector at right location by following NFPA 2 guidance.

The requirement of gas detection with equipment interlock and HVAC unit is one of the potential options for mitigating the explosion risk for greenfield project. This needs careful consideration by following local installation codes and regulations. The placement, the technology and the number of gas detectors required for total coverage must also be considered. A poorly designed and maintained gas detector system can contribute to an explosion hazard by providing a false sense of security. A gas detector system must function as the manufacturer intended for this solution to be feasible.

Conclusion

Hydrogen production is rising in popularity globally due to the increasing demand for clean energy. At same, hydrogen as an alternative fuel is highly flammable gas and can cause fire and explosion if it not handled properly. The best way to mitigate a hydrogen explosion hazard of hydrogen system located in indoor is by eliminating loss of containment and proper ventilation. A good ventilation design will ensure that any releases that may occur in normal operation will be rapidly dispersed by air movement and displacement.