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# Hydrogen Equipment Enclosures: What is the best practice for their successful design?

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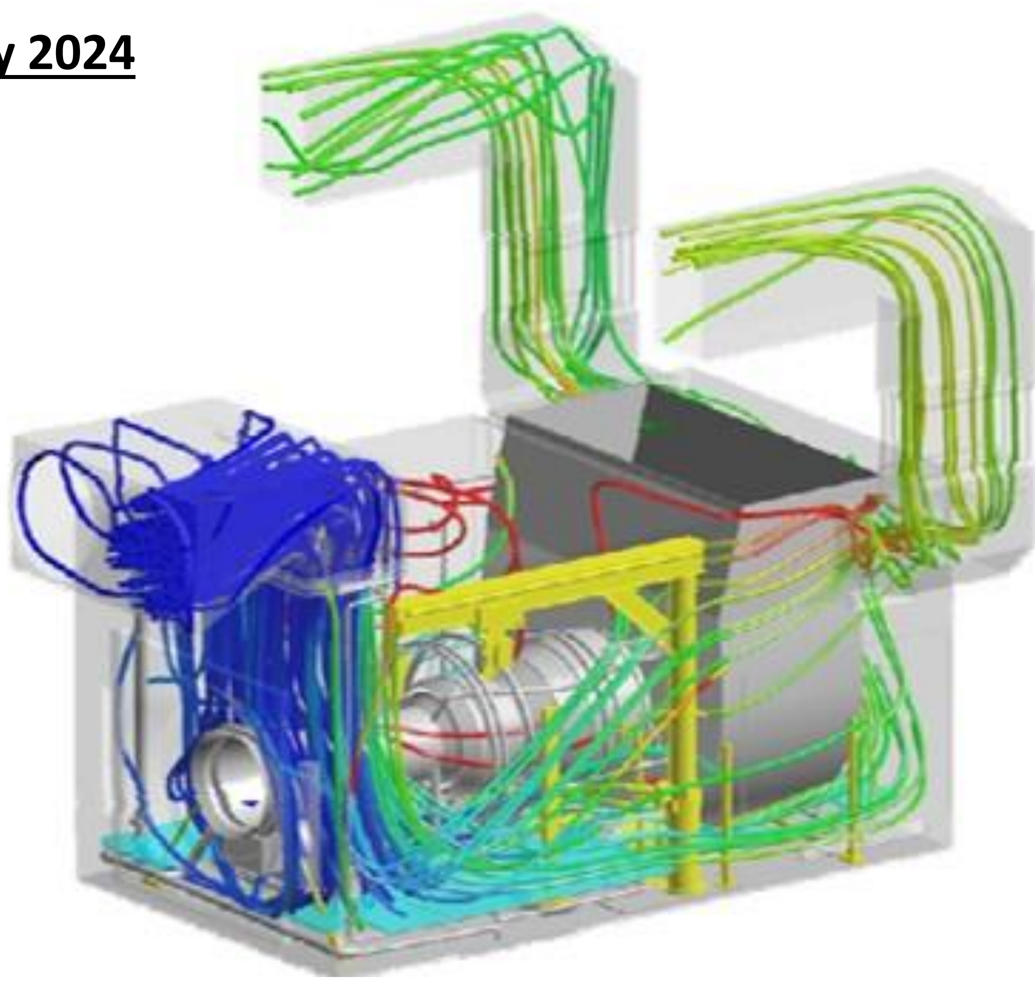

Hydrogen Enclosures White Paper

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# Introduction

A global transition to increased use of Hydrogen is in its infancy. This is being driven by the need to reduce carbon emissions. Whilst significant efforts are being made into producing different equipment that is compatible with Hydrogen, more consideration is required into the effects on Ancillary Equipment and Installations.

Principle ancillary systems can include:

- Enclosures (both compact integrated enclosures (CABS) or larger buildings)
- Enclosure Ventilation Systems
- Gas Detection and Fire Suppression Systems

This white paper outlines the current technology maturity for Hydrogen applications and defines a best practice for design of new Hydrogen Capable Enclosure system.



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# Background

An equipment enclosure provides protection from the environment and can typically take the form of an insulated steel box (for more compact integrated solutions) or larger portal frame buildings. Ventilation is provisioned either as a forced fan driven system or open/natural vented.

The requirement for an enclosure can be to:

- Reduce Noise
- Manage Heat Rejection (cooling airflow for equipment)
- Create a Hazardous Area Zone
- Protect equipment from environment.
- Provide an enclosed space for the release of extinguishant in the event of a fire.

Typical Hydrogen supplied equipment includes:

- Electrolysers
- Reciprocating Engines
- Gas Turbines
- Gas Compressors
- Boilers



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# Selection of Ventilation Airflow

There are two main considerations that can determine the level of ventilation airflow required:

1. **Maximum Enclosure Temperature** (dependent on equipment heat reaction, max temperature capability of critical equipment inside enclosure)
2. **Level of Dilution Ventilation required** by safety case to manage potential fuel leaks.

## Maximum Enclosure Temperature

Some equipment (e.g. rotating equipment such as gas turbines, compressors) that is contained within an enclosure will release a considerable amount of heat. If the equipment is to be maintained at a safe operating temperature, then a sufficient flow of cooler ambient air must be introduced to the enclosure and the warmer air exhausted.

Depending on the amount of heat rejection of equipment, the flow of air needed to cool the equipment may be such that natural ventilation is not sufficient and a set of fans will be required to drive the ventilation air through the ductwork.

Typically, this system will include filtration of air on inlet, utilize fans, silencers, and integrate with fire retention dampers. Depending on required redundancy for ventilation system, for high integrity systems often there will be 2 fans in parallel configuration, one fan as a standby.

Since the ventilation ductwork provides a path for the equipment noise to escape from the enclosure and the fans are also a considerable noise source, both the intake and exhaust ducts will be equipped with silencers to reduce the noise being emitted from the intake and exhaust aperture. Additionally, the ductwork may be externally clad to reduce the breakout of noise into the environment.

## Dilution Ventilation

Fires and explosions represent a significant hazard for hydrogen equipment installations. Quantitative Risk Assessment methods are employed to understand the level of fuel leak risk and hence define requirements / risk mitigation for the design of enclosure/ventilation system that will reduce this risk to a tolerable level.

As an example, ISO21789 the functional safety standard for Industrial Gas Turbines employs a methodology of dilution ventilation. Dilution ventilation shall be applied to ensure that areas of stagnant or insufficient ventilation are minimized so that in the event of a flammable gas leak, the potentially explosive cloud is diluted by jet mixing with the surrounding air and the mixture is immediately and effectively removed by ventilation.

It should be noted that ISO21789 methodology does have gaps regarding Hydrogen, but the philosophy of dilution ventilation it employs is still valid. Care needs to be taken on target cloud sizes and associated over pressure indicated by this standard, as this it not consistent with test data observed for Hydrogen explosions.



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In ISO21789, ventilation is defined such that explosive concentrations are restricted to the mixing zone and its immediate vicinity and shall be sufficiently small relative to the size of the enclosure. For a specific enclosure, the maximum allowable explosive gas cloud volume arising from a leak is to be limited to the smaller of 0.1% of the enclosure volume, or 1m3 at the 100% Lower Explosive Limit (LEL) contour.

This limit on the allowable gas cloud volume ensures that in the event of ignition, the maximum overpressure from an explosion is limited such that the pressure rise consequences can be contained. But Hydrogen introduces higher risk of overpressure, and aperture areas for release of this pressure in the enclosure become important.

Dilution ventilation is often used in association with gas detectors, since it is designed to dilute reasonably foreseeable leaks within a defined range.

Flammable gas detection is configured to detect the presence of gas to enable an emergency shutdown before the maximum allowable gas cloud is exceeded. Effective distribution of ventilation air is more important than the ventilation quantity, where necessary ventilation distribution ducts may be used to direct air to points of stagnation or recirculation.



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# Hydrogen gas properties

The following table shows the properties that are pertinent to explosion safety and the perceived impact on explosion risk for Hydrogen versus Methane. Generally, all properties contribute to an increase in the risk apart from the relative density as this is like to aid dilution ventilation. There is a reduction in the conditions at which Deflagration to detonation transition (DDT) takes place with Hydrogen.

| Property | Methane | Hydrogen | Explosion risk |
|---|---|---|---|
| Auto-ignition temperature (AIT) | 600°C | 560°C | INCREASED |
| Lower explosion limit (LEL) | 4.4% | 4% | INCREASED |
| Lower explosion limit (UEL) | 17% | 77% | INCREASED |
| Ignition energy (Deflagration) | 0.25mJ | 0.017mJ | INCREASED |
| Ignition energy (Detonation) | 230J | 0.01J | INCREASED |
| Estimated overpressure for typical GT enclosure (stoichiometric gas cloud at 0.1% enclosure net volume) | 10mbar | 40mbar | INCREASED |
| Gas detectability/sensor technology | IR and Catalytic Bead | Catalytic Bead only | INCREASED |
| Relative leak rate for a give hole size (methane = 1) | 1 | 2.8 | INCREASED |
| Relative density (air = 1) | 0.55 | 0.07 | DECREASED |
| Flame Speed | ~30-40 cm/sec | ~200-300 cm/sec | INCREASED |



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# Enclosed Hydrogen Explosion Over Pressure

Over pressures measured in vented deflagration tend to :

1. Increase with increasing reactivity of the mixture
2. Decrease with increasing vent (aperture) area
3. Increase with increasing opening pressure and specific weight of the venting device (e.g. explosion relief panels)
4. Increase with increasing distance from the point of ignition to the vent opening
5. Stratified mixtures can produce significantly higher explosion pressures compared to homogeneous mixtures
6. Flame propagation past obstacles results in increased flame surface area and enhanced turbulence in the wakes – the net result is higher overpressures



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# Best Practice Check List

1. Conduct a **Quantitative Risk Assessment** to determine a realistic upper limit to leak size that system needs to be designed for.
2. Consider the following 3 elements which contribute in combination to the **Safety Case**.


3. Provision **Dilution Ventilation** (based on principles of ISO21789)
4. Use **Hydrogen buoyancy** to your advantage, vent exits should be high in enclosure
5. **Minimize stagnant regions** where there is insufficient ventilation
6. Consider **Purge Systems,** for fuel lines and ductwork
7. **Rising line of ductwork**, to avoid trapped volume of fuel gas leak
8. **Large Vent areas** (pointing in a safe direction, typically vertically upwards) to minimize overpressure of an ignition event. Additional areas can be provided by Explosive Panels, but these must be low inertia, fast opening devices.
9. **Zoning** – Keep areas of higher probability leaks away from hot ignition sources
10. Ensure **Structural Capability of Enclosure** meets requirement of overpressure from internal blast event.
11. Provision Hydrogen Capable Gas Detection
12. Provision **Fire Suppression system** that is able to extinguish a Hydrogen fire at the size required by QRA assessment
13. Consider **Fire & Gas System Control Logic**, e.g when is fuel supply valves closed, will fuel supply valves operate quickly enough, when is equipment shut down triggered, when is fire suppression activated, what is Emergency Shut down sequence and when is it triggered?



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