Key Learning Points Hydrogen Incident

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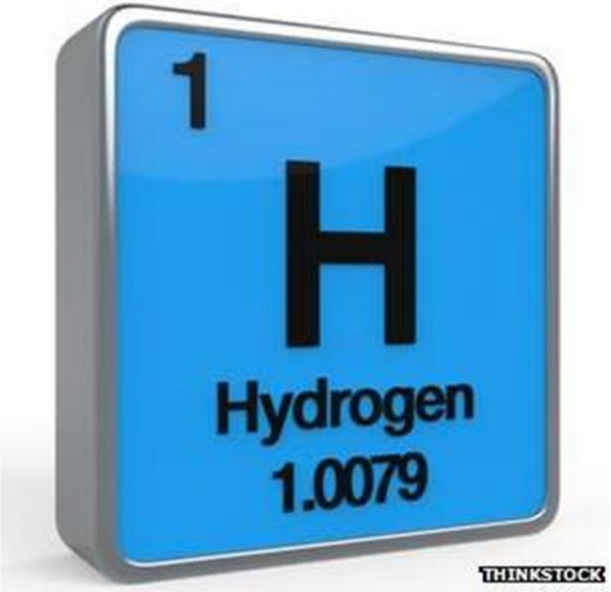
Vision

Gexcon – the leading global partner in dispersion, fire, explosion safety and risk management

Hydrogen Experience

- Over the latest years, we have carried out substantial research into the behaviour and characteristics of Hydrogen in a safety perspective, and we have been involved in a number of projects concerning Hydrogen safety, both in the marine and other industries.
- We have also developed a hydrogen module to our in-house simulation tool FLACS (FLame ACceleration Simulator) where the results of our research has been combined with literature to provide a credible and traceable tool for prediction of accidental effects in the event that hydrogen is released and ignited.
- Currently involved in several project concerning use of Hydrogen in
  - Maritime applications
  - Metallurgy
  - Nuclear industry
  - Vehicle fuelling



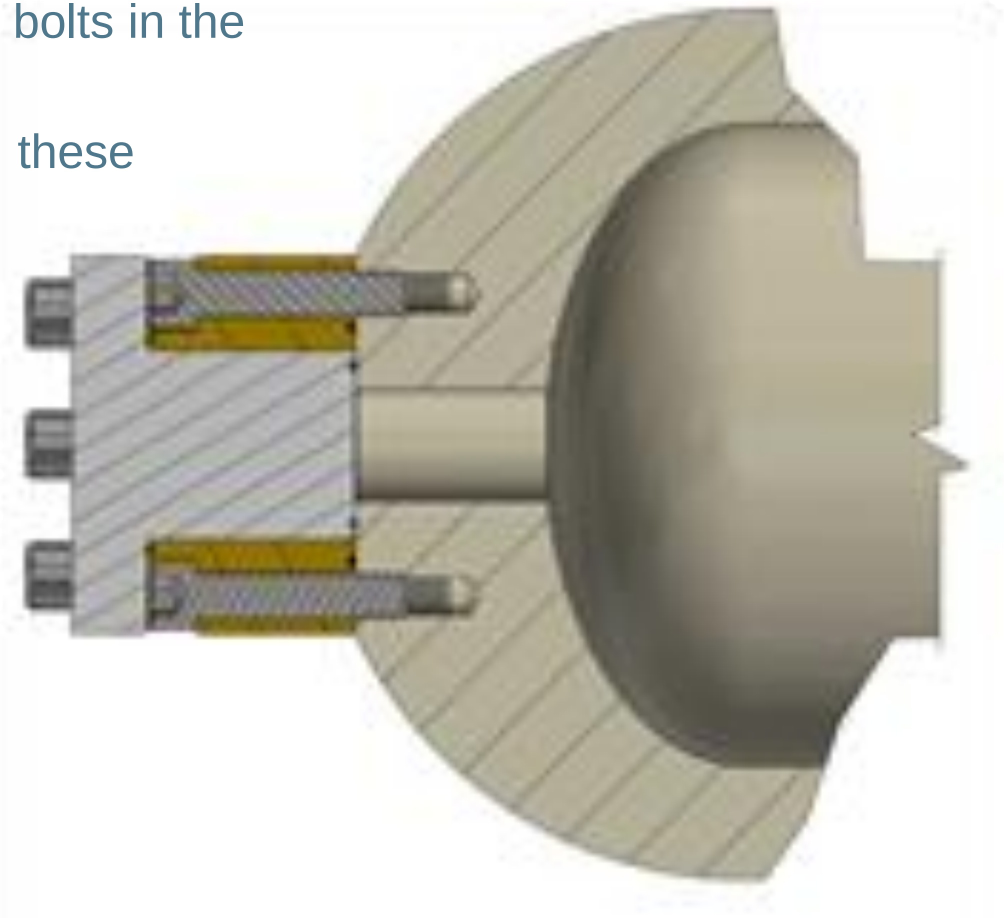
Hydrogen Incident

- In the late afternoon of 10 June 2019, a leakage and subsequent explosion occurred at the Hydrogen Refuelling Station located in Sandvika near Oslo, Norway.
- The explosion was followed by several fires within the facility.
- The initiating cause for the incident was a large leakage in a storage cylinder, normally operating at 950 bar.
- Gexcon was contracted to investigate the root cause of the incident and to propose mitigating measures for implementation in existing and future facilities.

Why the leakage occurred

- The most likely cause for the leakage was undertorqued bolts in the plug assembly at the end of the cylinder.
- Significant effort was made to explore other possibilities, these mechanisms were ruled out through the investigation.
- The leakage started small and developed over time, possibly due to the follwoing mechanism;

  - ✓ Insufficient bolt torque
  - ✓ Insufficient compression of o-ring
  - ✓ Motion of o-ring under pressure cycles
  - ✓ Friction/wear
  - ✓ Small damage to o-ring
  - ✓ Complete failure of o-ring



Ignition

- Several possible mechanisms for ignition have been investigated. The mechanisms comprise
  - Spontaneous ignition due to thermodynamic effects (literature search conducted)
  - Agitation of particulate matter (gravel)
  - Exposure to non-ATEX mechanical equipment (e.g. drive belt)
  - Exposure to non-ATEX electrical equipment (e.g. cooling fans, pumps, electrical cabinet)
- All of the above mechanisms have had potential to ignite the leakage.
- Due to fire damage, there is no hard evidence at hand to support a decisive conclusion, but it is deemed that auto-ignition is the most likely mechanism.

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Explosion

- The explosion that took place at Sandvika involved somwhere between 1.5 and 3 kg of Hydrogen.
- For comparison, the experiement in the video involved about 700 grams

Key Learning Points

Could this leakage have been detected before the incident ?

- The answer to the question is probably «YES»

- There are several means to detect high pressure leakage
  - Hydrogen gas detectors – electrochemical
  - Acoustic detectors
  - Pressure monitoring of storage coupled with software algorithms
  - Thermal imaging coupled with software algorithms for pattern recognition

- Rigorous maintenance and inspection may uncover latent failures

Understanding auto ignition in high pressure hydrogen leakages

- A number of scientific articles describe how high pressure leakages of Hydrogen spontaneously ignite.
- We don’t fully understand why.
- It is <u>suspected</u> that the phenomenon is related to supersonic flow through the aperture of the leakage, where it is suspected that the sonic shocks may cause local high energy concentration able to bring Hydrogen above its auto ignition temperature.
- However, this is yet to be properly documented.

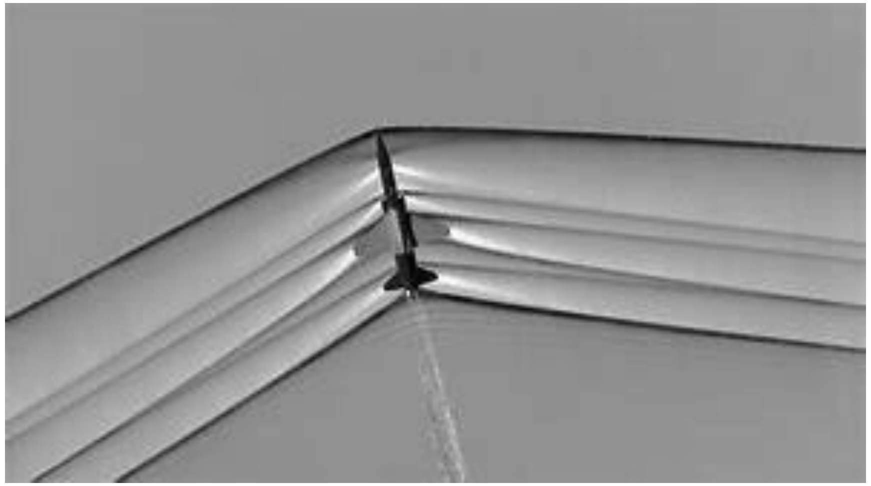

Image of sonic shocks
using Schlieren apparatus

- In short – more research is needed to fully understand this.

Could supersonic flow be prevented ?

- Many of the applications being considered for Hydrogen involve high pressure storage
- If the hypothesis of auto ignition being caused or exacerbated by supersonic flow, is there any way we can prevent this effect?
- In my <u>opinion</u> – YES
- Building sealing systems with longer leakage paths from high pressure to atmosphere would make the pressure drop occur over a larger distance and reduce the risk of supersonic flow.

- But again – this needs to be confirmed by research.

How do we learn as an industry?

Adopting lessons learned

- Flight, in its infancy, was a very perilous activity
- The aviation industry has consistently applied lessons learned from accidents and near misses, and shared these lessons across the industry
- These days, flight is one of the safest modes of mass transport available.

CHALLENGE

How can the Hydrogen industry act so that lessons are shared and safety promoted as a collective effort?

QUESTIONS?

Thank you for your attention

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