Fire tests carried out in FCH JU Firecomp project, recommendations and application to safety of gas storage system
Composite pressure vessels
@Air Liquide
Structure of the AL Group

1. Engineering & Construction
   - Designing and building state-of-the-art production units for Air Liquide as well as for third-party customers.

2. Large Industries
   - Investing long-term to produce large quantities of gases for our customers and to meet the Group's needs.

3. Part of the production capacity of Large Industries is used to serve Industrial Merchant, Healthcare, Electronics and Global Markets & Technologies within a geographic radius of about 250 km. Products are distributed in liquid form (in cryogenic tanks) directly to storage units on the customer's premises or in gaseous form (in cylinder) depending on the quantities required. Gas production is actually a local activity, as gases are not transported over long distances, with the exception of some rare and specialty gases used mainly in electronics.

   - **ASU**: Air Separation Unit
   - **SMR**: Hydrogen separation production unit (Steam Methane Reformer)
   - **On-site**: Small local production unit

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Fire tests carried out in Firecomp project, recommendations and application to safety of gas storage system.
AL in the hydrogen value chain

Production → Storage → Transport → Distribution → Applications & Customers

Fire tests carried out in Firecomp project, recommendations and application to safety of gas storage system.
AL in the hydrogen value chain

- Distribution
- Transport
- Storage
- Production

Composite cylinders for AL supply chain operations

Composite cylinders as customer’s storage to be filled

Applications & Customers

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R&D activity in composite pressure vessels

R&D knowledge covering all aspects of cylinder’s lifetime within AL operations
Targeting a safe & efficient use of composite cylinders

- Ensure structural integrity of vessels through their lifetime, beyond existing standards
- Assess the consequences of accidental events and mitigate the industrial risk
- Reduce the total cost of safely operating composite pressure vessels through better understanding
Fire risk with composite cylinders

- In fire, burst due to Inner pressure increase
- In fire, burst due to Material degradation

- Shorter time to burst
- High energy content
- No pressure increase

Need to adapt fire strategy
2

FireCOMP project and results
Fire COMP

Pre-normative research on fire safety of composite pressure vessels

- Risk analysis
  - Identification and quantification of fire scenarios depending on applications
  - Comparison with metallic cylinders

- Experimental work
  - Heat transfer, thermal degradation & loss of strength
  - Material (lab) & cylinder (full) scale
  - Bonfire tests matrix based on relevant scenarios

- Modelling
  - Thermo-mechanical behaviour of the vessels
  - Model validated by full scale fire tests
Calibration of thermal aggression

Net heat flux absorbed by the metallic cylinder

Average 90 kW/m² between 200 s and 400 s

Calibration of heat flux and temperature

Temperatures recorded at 5 cm outside of the cylinder display a good homogeneity and fluctuate between 800°C and 1000°C
Calibration of thermal aggression
H₂ burners vs. pool fire

For 36 L cylinders, the injection flow rates retained allow to reach the same temperatures as with classical pool fire.

With results that meet bonfires performed in the past.
Fire tests carried out in Firecomp project, recommendations and application to safety of gas storage system

- Hydrogen gas fire is a realistic scenario
- Gas fires are easier to calibrate and more reproducible than pool bonfire
- Calibration tests performed on steel cylinders to optimise:
  - The confinement
  - The needed hydrogen flow rate
  - The oxygen injection
- Complete definition regardless of the cylinder size

Hydrogen gas burners
4 burners, with each
1.5 g/s hydrogen
0.5 g/s oxygen

Oxygen alimentation points
Results of fire tests on Hexagon 36 L type IV vessels without any protection

- **Two failure modes**
  - Burst when initial pressure 525 or 700 bar
  - Leak when initial pressure 100 or 250 bar

- **Cylinders equipped with thermocouples**
  - Wound inside the composite
  - Slightly decrease the time to burst
  - Allowed checking the heat transfer model

- **Good reproducibility**
  - Two vessels @700 bar burst at rsp. 238 s and 240 s
  - Temperature evolutions inside composite thickness are similar
FireCOMP recommendations and example of application
Methodology proposed for fire testing

**Current practice** is to test both cylinder and TPRD simultaneously and **regardless of their integration** in a structure.

FireComp project aimed at understanding the behaviour of a composite pressure vessel in fire. Hence it is proposed, when qualifying a cylinder, to focus on getting information on what the cylinder can endure.

The proposed methodology is to separate

1. **Performance of the cylinder alone**
   Fire test without protection in order to establish a **pressure relief curve** = “safe” pressure vs. time zone in a fire
   - **By cylinder manufacturer**, during **qualification** process

2. **Safety of the complete structure**
   (e.g. Bundles, trailers, cars, ...)
   With a safety **strategy depending on the risk analysis** for the application; possibly including metallic frames, protections, fire detectors, pressure relief system...
   - **By cylinder end-user**, when designing a **fire safety strategy at structure level**
Safe pressure relief curve

The pressure relief system shall be designed for pressure to always be in this area in case of fire.
Safe pressure relief curve
Possibly determined using only one tank...

Information can be found in the following paper and its references:
Example of application
AL hydrogen bundle

High pressure bundle
- 4 * 143 L @700 bar
- Safety distance for 50 mbar overpressure in case of burst: 34 m => not acceptable for this application

Fire tests on cylinder alone
- Measure of the time to burst / leak
- Too short time for an acceptable flame length if ignited release => metallic frame to delay the fire

Fire tests with the frame
To assess the delay provided

The frame also makes the fire detection by TPRD more reliable and protects vs. local fires
Summary of the fire safety strategy for the bundle

- TPRD activation (estimated)
- Fire starts
- Burst
- Leak
- Conservative limit between burst and leak failure modes (leak was observed at 350 bar)
- Cylinder without any protection failure times
- Protective effect of the metallic frame: delays the failure
- Pressure in bundle approx. 600 L water volume Initially 700 bar
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Thank you for your attention.