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Report on available information including existing standards for bonfire test of H_2 tank structures

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Contents

1. General Remarks

1.1. Hydrogen and other fuel gases

Making a car run on a normally gaseous instead of a liquid fuel is not a quite new idea. LPG (Liquefied Petroleum Gas, mixtures of propane and butane) is rather common in countries like The Netherlands, France, and Italy since quite a while. LPG, however, is a gas which liquefies under moderate pressure at ambient temperatures and is thus no good model for hydrogen.

Natural gas is much more similar to hydrogen, and we have today a rather extensive experience with this fuel. Many requirements for the fuel tanks are similar. The gases as well are rather similar in their chemical and safety technical properties.

But there is an important difference: the energy density of hydrogen gas is smaller than that of natural gas under the same pressure. Car makers aim at maximum operating pressures of 70 MPa in order to achieve a range of the car which is at least comparable with that for common liquid fuels on fossil basis.

1.2. Tanks from composite organic materials

A recent development in pressure equipment technology is the arrival of cylinders and other vessels made not or not only from metal. This started with metal cylinders partially or totally wrapped with fibre reinforced polymers in order to reduce weight. From there it was a logical step towards the tank which comprises little or no metal. Use of such tanks is by no means restricted to fuel tanks, but to every application where dead weight must be avoided, for example breathing apparatus for fire fighters.

Such a tank comprises a core which is either polymeric or made from a thin metal sheet. In the latter case it serves as a barrier against diffusion of the gas through the walls which over longer times may be considerable for such a tank. Layers of the fibre reinforced resin are then wrapped around the core. The wrapping process is a key to the quality and reliability of the tank. The way in which the valve thread or other equipment are fitted in is crucial for safety because if there is a failure of the tank itself it happens or starts usually at places like this.

Both natural gas and hydrogen as fuels rely also heavily on the use of tanks made from fibre reinforced polymers instead of metal in order to reduce the dead weight. In the case of hydrogen in particular this can be considerable and reduces amount of energy available for driving. Both the design and manufacturing of the tank itself and its integration into the car contribute to the safety of drivers and passengers.

Both studies and experience indicate that such tanks are on the same safety level than conventional gas cylinders made from metal. But the possible failure mechanisms are quite different ones. Fibres may break, the bond between fibre and matrix may be lost, and sheets may separate from each other. All this can not happen in metal. Cracks, corrosion, and material incompatibility with hydrogen (embrittlement, enhanced crack growth), on the other hand, are problems unknown to polymers.

While the metal cylinder has been around for more than a century the operational experience with polymeric tanks is comparatively short. This is why design, manufacture, and recurrent tests are more strict and frequent here than for metal. Everybody hopes that the experience gathered this way and by more research and development work will contribute to achieving a state in which the test work on polymer pressure vessels is not more extensive than for metal cylinders.

1.3. Car tanks

Tanks for gaseous car fuel differ in terms of safety from stationary pressure vessels. Road traffic is a dangerous environment with risks very different from those for stationary operation. Accidents affect not only specialized workforce, but the general public. Safety is thus an important topic in traffic technology anyway.

New fuels or new technologies in general are frequently received with a certain scepticism by the public, in particular when they comprise changes as fundamental as the phase of the fuel. Demonstration of safe use is usually the best strategy to overcome this.

2. Tests for hydrogen fuel tanks

2.1. General procedure

For a private person buying a car there is usually no need to get an approval for it. (What is called “Zulassung” in Germany, or maybe “approval” elsewhere, is in reality not an approval at all but simply a registration of this car for that owner.) There is a type approval for this car, which is provided by the manufacturer. It is his responsibility to prove to the authorities that this car type responds to all applicable regulations, whether safety relevant or others. The type approval covers everything the manufacturer offers for this type of car, and also things which the owners usually add or change.

Major changes of the car (tuning) may move it outside the scope of the type approval. The owner must then himself present the car to the authorities and demonstrate that it still complies with the rules.

Converting a car from liquid to gaseous fuel is definitely a major change which is not covered by the type approval. Almost all manufacturers produce now natural gas cars in series and have type approval for them. Hydrogen cars, however, exist only in a very limited number. Making 30 or 50 cars is not called “serial production” in the car world; this starts at maybe 50.000 per year. So for the time being every individual hydrogen car must obtain an individual approval. Presenting them in batches of 10 or 15 may help saving work, but is still very far away from a type approval.

2.2. EIHP

The state of things described above may be bearable as long as there are only a few prototype cars running under close supervision of the manufacturers. But for marketing them as a mass product there must be a way to get a type approval.

The approval process must also be agreed upon on an international basis. This is particularly important for Europe because here it much more common to cross the national borders with the private car than elsewhere.

Since some manufacturers predict the start of the serial production for as early as 2010 and since making internationally harmonized regulations is a rather time-consuming process we can not simply wait. A few years ago the European Union started the project EIHP which had just this objective. Experts from different countries laid the foundation for an international code on the basis of which cars running on liquid or compressed hydrogen can be approved in all countries.

The results of the EIHP work were to be submitted to the ECE (Economic Commission for Europe), a sub-organisation of the United Nations. From the United Nations the code would be forwarded top-down to the UN member states who would have to adopt this into their national law.

At this time the progress along this way is not as fast as desired, and some countries will take national initiatives. It is to be hoped that they all will in due time come together on a common basis. And it is very likely that this basis will have a great similarity with the EIHP papers. Since there is no other specialized proposal for this field EIHP has already become a practical standard for the test of hydrogen fuel tanks.

2.3. Test program

Approval test procedures for containers are dealt with in Annex 7 part B of the Draft ECE Compressed Gaseous Hydrogen Regulation, quoted after the currently valid Revision 12b dated 12. October 03. The paper is added as an attachment. Annex 7 part B starts on page 70.

Tanks are divided into the generally known four types:

- Type 1: Seamless metallic Container.
- Type 2: Hoop Wrapped Container with a seamless metallic Liner.
- Type 3: Fully Wrapped Container with a seamless or welded metallic Liner.
- Type 4: Fully Wrapped Container with a non-metallic Liner.

The test program consists of two parts, one for the materials and one for the finished tanks. Not every test is applicable for every type of tank. Hydrogen compatibility for example is an issue only if metals are used, so full-polymer tanks of the type 4 are exempted from this. Chemical exposure, on the other hand, is not important for full-metal tanks. The table indicates which type will be subjected to this test.

Tests of container materials	**1**	**2**	**3**	**4**
B1 Tensile Test				x
B2 Softening Temperature Test				x
B3 Glass Transition Temperature Test		x	x	x
B4 Resin Shear Strength Test		x	x	x
B5 Coating Test	x	x	x	x
B6 Coating Batch Test	x	x	x	x
B7 Hydrogen Compatibility Test	x	x	x	
B8 Hardness Test	x	x	x	

Tests of finished containers	**1**	**2**	**3**	**4**
B9 Burst Test	x	x	x	x
B10 Ambient Temperature Pressure Cycling Test	x	x	x	x
B11 Leak-Before-Break (LBB) Performance Test	x	x	x	x
B12 Bonfire Test	x	x	x	x
B13 Penetration Test	x	x	x	x
B14 Chemical Exposure Test		x	x	x
B15 Composite Flaw Tolerance Test		x	x	x
B16 Accelerated Stress Rupture Test		x	x	x

B17 Extreme Temperature Pressure Cycling Test		x	x	x
B18 Impact Damage Test			x	x
B19 Leak Test				x
B20 Permeation Test				x
B21 Boss Torque Test				x
B22 Hydrogen Gas Cycling Test				x
B23 Hydraulic Test	x	x	x	x

Type 4 tanks are obviously tested most intensive, for reasons easy to understand.

2.4. Bonfire Tests

The exact test program is like this:

B12.1 Sampling

The test applies to all Container Types.

Type approval testing - Number of Finished Containers to be tested: Minimum 1

B12.2 Procedure

Special consideration shall be given to safety when conducting this test.

The Container shall be pressurised to Nominal Working Pressure with hydrogen or a gas with a higher thermal pressure build up. The pressurised Container shall be tested as follows:

i) Place the Container in a horizontal position approximately 100 mm above a uniform fire source with a length of 1.65 m. The arrangement of the fire shall be recorded in sufficient detail to ensure the rate of heat input to the Container is reproducible. Any failure or inconsistency of the fire source during a test shall invalidate the result,

ii) If the Container is ≤ 1.65 m, it shall be positioned centrically above the fire source,

iii) If the Container is > 1.65 m and it is fitted with a Pressure Relief Device at only one end, the fire source shall commence at the opposite end,

iv) If the Container is > 1.65 m and it is fitted with Pressure Relief Devices at more than one location along its length, the centre of the fire source shall be centred midway between those Pressure Relief Devices that are separated by the greatest horizontal distance,

v) If the Container is > 1.65 m and it is additionally protected by thermal insulation, 2 fire tests shall be performed at Nominal Working Pressure. The Container shall be positioned centrically above the fire source in one test, while the fire shall commence at one of the Container ends in the other,

vi) Metallic shielding shall be used to prevent direct flame impingement on Container valves, Fittings, or Pressure Relief Devices. The metallic shielding shall not be in direct contact with the Pressure Relief Devices. Any failure during the test of a valve, Fitting or tubing that is not part of the intended protection system for the design shall invalidate the result,

vii) Surface temperatures shall be monitored by at least three thermocouples located along the bottom of the Container and spaced not more than 0.75 m apart. Metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm x 25 mm x 25 mm,

viii) The fire source shall provide direct flame impingement on the Container surface across its entire diameter immediately following ignition,

ix) Thermocouple temperatures and the Container pressure shall be recorded at intervals of ≤ 10 seconds during the test,

x) Within 5 minutes of ignition and for the remaining duration of the test the temperature of at least one thermocouple shall indicate at least 590 ℃,

B12.3 Requirement

The Container shall only vent through the Pressure Relief Device(s) and shall not rupture

B12.4 Results

The results shall be presented in a test summary, e.g. Table 7A.4 of this Annex, and shall include the following data for each Container as a minimum:

i) The elapsed time from ignition of the fire to the start of venting through the Pressure Relief Device(s),

ii) The maximum pressure and time of evacuation until a pressure ≤ 1.0 MPa is reached.