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GASTEF: The JRC-IE Compressed Hydrogen Gas Tanks Testing Facility

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1 Introduction

Hydrogen can be stored in many ways as metal hydride tanks, compressed gas, cryo-liquified, carbon nanotubes, gas micro spheres, liquid carrier or chemical storage. However, for on-board applications, both compressed gas and liquid hydrogen have established themselves as state of the art.

The storage of gases under pressure, including hydrogen, is a well-known technology. Nonetheless, the use of hydrogen tanks in vehicles and in particular the challenge of using very high pressures, demands stringent regulations supported by safety and performance studies. Requirements to qualify storage systems for on-road passenger vehicles have been under development primarily by the SAE International and ISO committees (respectively SAE-J2579 [1] and ISO15869 [2]). The push to develop safety standards for hydrogen storage well before commercialization is driven by two factors. First, acknowledging that on-road safety is of highest priority, requirements are being developed a-priori, without waiting for any lessons learned from on-road experience. Second, taking into account that there is a high need for rapid insertion of new technologies into the marketplace, storage requirements must be capable of qualifying novel technologies for reliable and durable performance under broad conditions of use. Setting up qualification test campaigns with conditions that take into account historical failure mechanisms is helpful but not sufficient. Instead a comprehensive approach to defining extreme conditions of on-road vehicle service is required. Storage systems must function both under the stresses of normal vehicle operation and under externally imposed stresses.

Today’s state of the art for hydrogen storage comprises 35 MPa (350 bar) and 70 MPa (700 bar) compressed gas tanks. Carbon fiber fully wrapped-reinforced tanks are already in use in prototype hydrogen-powered vehicles. Two types of inner liners are typically used: metal (aluminium, Cr-alloys) ones in “Type 3” storage pressure vessels and high molecular weight polymer in “Type 4” tanks, as described in ISO 15869 [2]. The application of such materials comes from the need of guaranteeing impermeability of the inner liner to the hydrogen molecules whilst having the tank being as lightweight as possible.

Both SAE 2579 and draft ISO 15869 propose the following tests for compressed hydrogen storage tanks:

- Sequential exposure to impact, chemicals and cyclic stresses
- Sequential exposures to static high pressures (simulates vehicle parking) and fuelling stresses
- Exposure to hydrogen fuelling under extreme ambient temperatures
- Simulated fuelling failure (i.e. overpressures) at the end of vehicle service

To carry out “expected-service performance verification tests” on full-scale high pressure vehicle’s tanks for hydrogen or natural gas, the JRC-IE has set up a facility, dubbed GasTeF (for Gas Testing Facility). In addition the testing of any other high-pressure components, such as valves and pipes, is also possible.

2 Facility Description

The JRC-IE compressed hydrogen gas tanks testing facility consists of a half-buried concrete bunker with an attached gas storage area. The bunker is analogous to bunkers designed for the storage of explosives such as dynamite; it has double walls of heavy-concrete and is covered by a three meter thick sand layer armored by geotextile every thirty centimeters so that it could endure a sudden energy release equivalent to 50 kg TNT [3]. In this way the impact of a potential hydrogen explosion in the vicinity of a nuclear installation is fully mitigated.

The bunker is divided into three parts: a service room, the compressor room and the test room, see Figure 1. All the relevant equipment inside the bunker is explosion proof zone 2 according to the ATEX 137 EC directive [4].

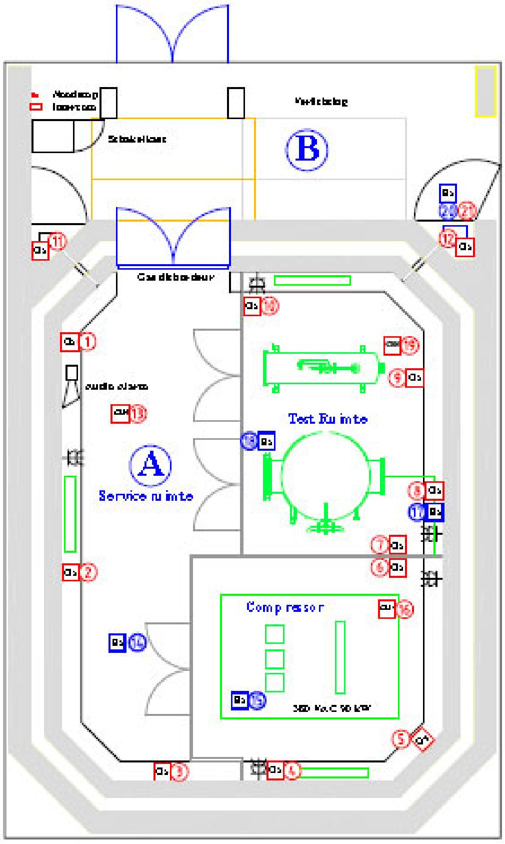

Figure 1: Overview of the inside of the GasTeF rooms and surveillance/safety devices.

The compressor room houses a two stages compressor enabling hydrogen or methane to pressurize and depressurize the test tank (i.e. fuelling and defuelling), Figure 2. The compressor is a piston machine built by Hofer and is able to fill a gas tank to a pressure of 88

MPa with a power consumption of 55 KW within 3 minutes. It is cooled using a closed water circuit that includes an air/water heat exchanger located outside the bunker. The compressor is equipped with its own PLC (Programmable Logic Controller) for full remote control. The PLC collects all signals from the machine and the cooler and performs its own continuous functional checks. Part of the information collected by the compressor PLC is transferred to the main control and automation PLC of the facility via a bi-directional link.

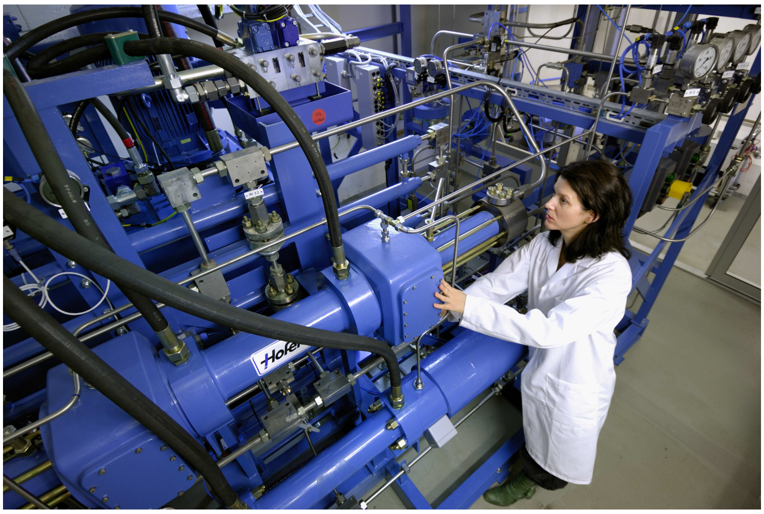

Figure 2: GasTeF compressor.

Figure 3: Safety pressure vessel.

In the test room a pressure vessel containing the component to be tested is placed, see Figure 3. The fuel tanks are inserted inside a sleeve which contains an inert gas (helium or nitrogen) and serves as a chamber for determining hydrogen permeation through the test tank walls. The hydrogen level in the sleeve is accurately determined using a gas chromatograph. The sleeve is placed into the safety pressure vessel which is filled with nitrogen at 5 kPa, so that hydrogen leakages will stay safely contained within a small volume. In the case of hydrogen/methane leakages outside the pressure vessel, into the test room, the emergency shut down procedure will automatically start.

The compressor and the test installations are linked with high pressure stainless steel piping. Besides control valves and pressure and temperature indicators, the system is equipped with safety valves and pressure reducers for emergency venting. The facility features also stacks for the controlled or urgent discharge of gases in the air.

The bunker is closed by a gas-tight inner door and after that by a hydraulically operated 40 tons massive concrete door sliding on Teflon plates. During tests, the bunker is deprived of oxygen by purging with nitrogen gas in order to prevent the occurrence of an explosive atmosphere created in the event of leakages. In normal operation the facility will be run fully automatically and the tests are operator controlled from a control room situated in an adjacent building.

Inside the bunker a number of gas detectors are strategically situated as Figure 1 shows. There are three types of sensors: Oxygen, hydrogen and methane content detectors, whereby all are placed inside each room in the bunker. The gas detectors form the heart of the safety monitoring system of the bunker, so special attention has been paid to their working logic:

In each room there are three oxygen sensors from which the signal of at least two must be valid in order to carry out the testing (the red squares in Figure 1). When the bunker is closed and filled with nitrogen, the oxygen content must be kept to a value less than 0.9%. On the contrary when the test is finished, the oxygen sensors have to measure more than 19%, before the bunker is allowed to be opened.

H_2 and CH_4 Sensors: There is a hydrogen and a methane detector in atmosphere inside each room and in the left niche of the bunker where the gas chromatograph is located (blue squares in Figure 1). In addition there are other H_2 and CH_4 sensors in the line going out from the sleeve to the gas chromatograph and to the exhaust stack. If one of the detectors measures a hydrogen content exceeding 80% of LEL the emergency shut down procedure is immediately triggered.

The emergency shut down procedure ensures that the three bunker rooms and all installation parts (piping, etc.) are purged with nitrogen gas. When all the hydrogen/methane has been vented-off, the ventilation system will fill all bunker rooms with air to regain a breathable atmosphere after which the concrete door can be opened and the bunker accessed.

3 Tank Performance Testing

GasTeF is designed to carry out the following experiments in both Type 3 and Type 4 cylinders:

Fast-filling cycling, in which storage tanks are fast filled and slowly emptied using hydrogen pressurized up to 70 MPa, for at least 1000 times to simulate their lifetime in a road vehicle. During the cycling process the tank is monitored for leaks and permeation rates using gas chromatography.

Static permeation measurements as a function of time on tanks filled up to 70 MPa and temperatures to 85 °C.

Figure 4 shows an example of fast filling experiment performed in GasTeF. In this case the target filling pressure was 350 bar and it took 2.5 minutes to fill in a 30 liters Type 4 tank. The emptying time was about 40 minutes. Figure 4 showcases how the tank temperature increases during the first filling cycles to reach a stable value of approx. +23 C° after six filling/emptying cycles.

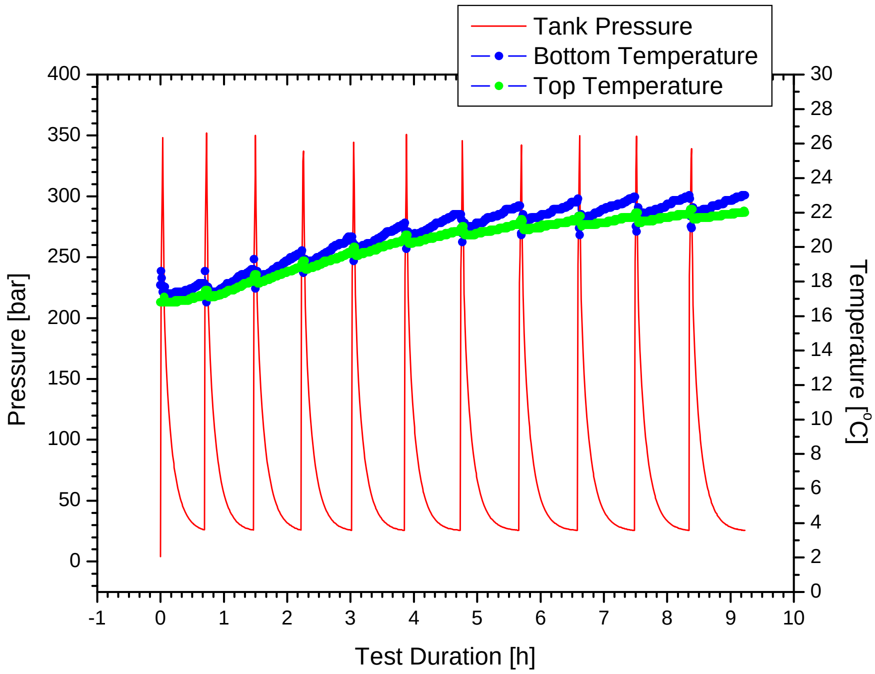

Figure 4: Example of a fast filling test.

A first example of a "permeation type" test carried out after the cycling depicted in Figure 4 can be seen in Figure 5. Here the tank pressure decreases sharply within the first 30 minutes and reaches an equilibrium pressure of 300 bar after 1.5 hours. The pressure drop seems to be primarily caused by the temperature decrease of the tank.

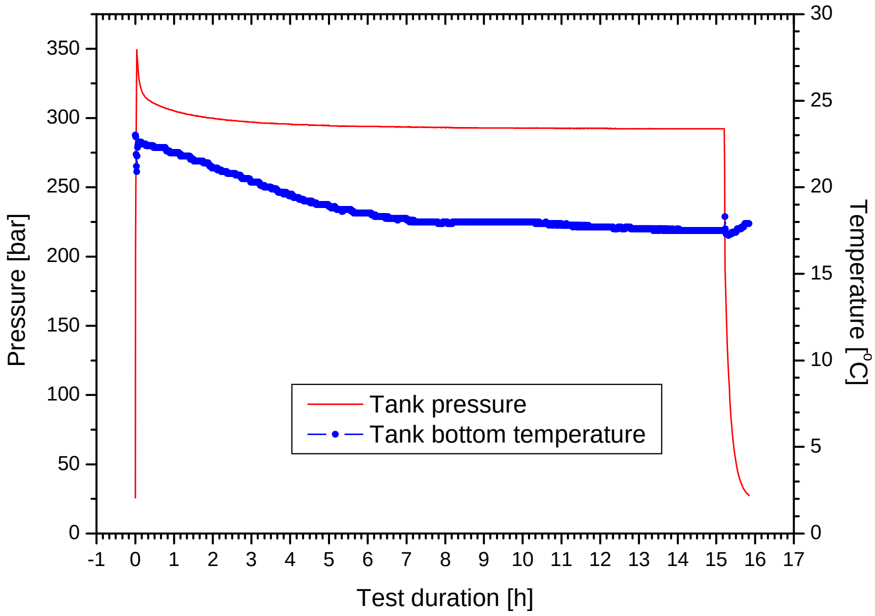

Figure 5: Example of a permeation test.

This activity is part of a more general effort aiming at assessing from a safety point of view existing and future regulation in the field, and in particular the measures drafted in the implementing European regulation on type-approval of hydrogen vehicle [5]. The GasTeF results will be applied to validate existing and future standards and will be used as input to pre-normative research for the development and improvement of performance characterization methodologies for hydrogen storage.

References

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[3] “Design of the hydrogen test facility of the Joint Research Centre in Petten, Netherlands” Ing. A.H. Verhagen, KEMA, Breda, June, 2003

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[5] Draft EC regulation, implementing Regulation (EC) No 79/2009 of European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles, Brussels July 2009.