Assignment – test program for maritime use of hydrogen

Background

Tests related to the safety of use of hydrogen as an energy carrier in the marine sector will be carried out with the aim to acquire knowledge of what has been identified as areas with limited knowledge by The Norwegian Directorate for Civil Protection (DSB) and the Norwegian Maritime Authority. The test results will contribute to knowledge for introduction of hydrogen as a marine fuel, thereby facilitating safe hydrogen use for the next generation of hydrogen-electric ships. There is less experience with the behavior of liquid hydrogen (LH_2). Hence, this assignment will focus on the behavior of liquid hydrogen. One of the goals of the tests is to acquire results that can be used for calibration and improvement of models that are used (as a basis) for and in risk assessments, with the main focus on maritime use of hydrogen. The results from all tests will be publicly available.

Those who will conduct the tests must demonstrate sufficient knowledge of hydrogen safety for the safe conduct of the tests. A document describing relevant characteristics and challenges is ISO/TR 15916 (2015).

The test plans should include description of how the test provider intend to ensure that the test results are as robust as possible; this may include, the need to repeat specific tests and/or measurement of specific test parameters to avoid random variations being misinterpreted. The starting point for the tests are leaks of liquid hydrogen, but it is assumed that liquid hydrogen will quickly evaporate and the development of and effects of cold gas therefore needs to be investigated. Monitoring of gas and ambient temperatures, gas concentrations and temperature response in relevant surfaces which are exposed, will therefore be part of the test setup for all cases.

Some modeling of the planned tests prior to carrying out the tests is needed to optimize the test program and the planned measurements. As an example, modeling of anticipated liquid pools before tests is needed to establish preferred locations for test probes.

LH_2 Outdoor Leakage Studies

Studies that simulate the spill from an outdoor bunkering operation should be conducted. The leakage should be at a rate similar to what can be provided by a standard bunkering operation (~50 kg/min) with a leakage point 1 m above ground. The total amount of spilled hydrogen should vary from test to test, but should not exceed 3000 kg. The tests should be performed in a confined area with container walls and a couple of single crates/containers as obstacles. The tests should be performed on a substrate of concrete as well as shipbuilding steel and aluminum. Shipbuilding steels should be tested with appropriate paint/coating.

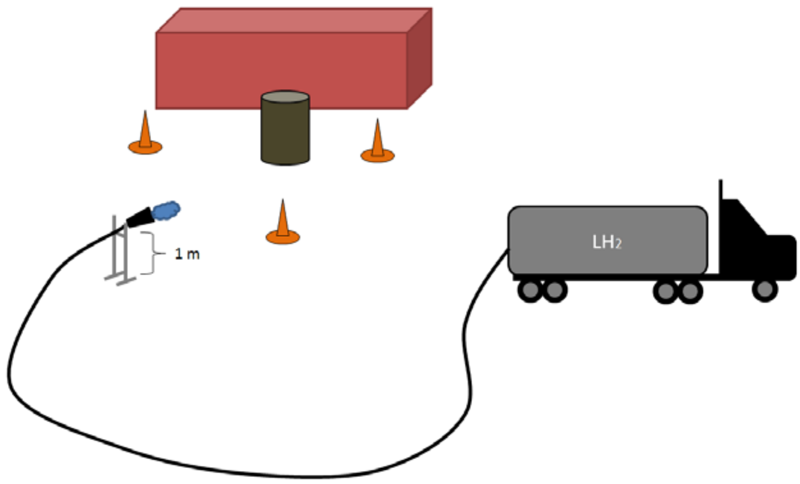

Fig. 1: Schematic test set-up of LH_2 outdoor leakage studies in an area with container wall/obstacles.

The following should be tested and recorded:

- The formation of a liquid pool including propagation, duration, ground temperature and heat transfer from the ground, should be recorded. Whether the liquid pool cease to grow due to equilibrium between the leakage and vaporization should be monitored. If no liquid pool is formed, the experimental setup/plan might need to be adjusted.
- Hydrogen concentration within the gas cloud (originating from the spill) should be recorded. The propagation and duration of the gas cloud should be recorded. Phase transition from liquid to gas, and evaporation rates are described elsewhere in the literature and will not be a focus in these tests. Wind speed, wind direction, and air humidity should be measured in the close vicinity of the release.
- The gas should be ignited in some of the tests, first by a low energy igniter, and then by a high energy igniter. The burning/deflagration/detonation of the gas should be recorded. The energy/pressure from any blast should be measured. Ambient temperatures should be measured.
- Changes in the materials (concrete, shipbuilding steel, aluminum) such as deformation, or cracking, should be investigated
- Possible condensation and freezing of O2 and N2 from the air should be observed (if it happens).

LH_2 Closed-room Leakage (TCS)

Leakage of liquid hydrogen in enclosed spaces is of particular interest as there is little documentation available on this topic. The outline of principle as shown in Figure 2 is a starting point for understanding the test case. The "closed space" where the tests will be performed should be representative for the "tank connection space" (TCS).

A TCS will typically have a volume of around 30 m^3, and dimensions of approximately 3x3x3m. At highest level on the top of the TCS there will be a tall ventilation mast. The height of the mast will depend on placement of tank/TCS. Height over open deck depends on obstacles. A vent mast length of more than 18 meters from TCS is not unusual. Some Norwegian gas ferries have ventilation masts that are more than 30 m from TCS to outlet. For the Norled ferry the length on GA is approx. 10-11 m. The TCS is normally ventilated with a vent in the lower corner, and another in the opposite upper corner. Inside the TCS there will be some constructs, which normally consists of valves, instruments, piping and equipment. Normally, there is one vaporizer for export of hydrogen from the TCS and one vaporizer for tank pressure maintenance, called PBU. 10-15 pneumatically operated valves, in addition to a number of hand operated valves, are fitted in the TCS. The tank and each piping segment are protected by safety valves, with their outlets connected to the ventilation mast.

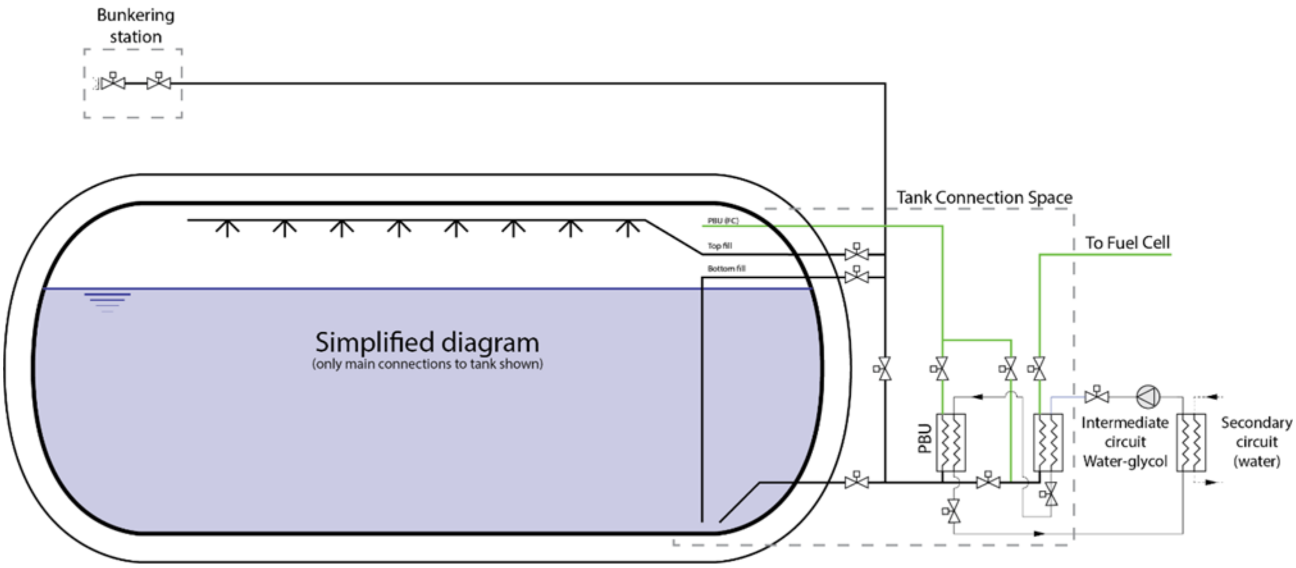

Fig. 2: Schematic diagram of LH_2 tank and tank connection space (TCS).

The following tests should be performed:

- A limited amount of liquid hydrogen sufficient for wall effects not to dominate (wall heat provides evaporation of hydrogen) should be released carefully into the TCS such that a realistic effect of cold gas in a closed space can be assessed. The discharge can be a continuous LH_2 spray (3-5 bar) into the enclosed space, but the rate (and duration) should be as high as is needed to form a liquid pool on the floor. The tests should be performed for cases where the atmosphere in the TCS is 1) atmospheric air, 2) nitrogen and 3) helium. The room should be pressure-tight, either with atmospheric or slight overpressure. The following parameters should be assessed:
    - Pressure build-up in TCS due to evaporation of LH_2
    - Concentrations of H_2 in TCS
    - Flow rate of H_2 out of the ventilation mast
    - Unwanted inflow of oxygen in an inert space (TCS), due to the eventuality of negative pressure.

    - Effects on the very TCS structure due to variations in pressure and temperature should be examined
- A few explosion tests should be performed within a solid box aiming at finding the explosion pressures that would result from different small and medium leaks. That would give valuable data for model validation. The box could be of concrete with explosive release panels.

Releases of cold H2 gas from ventilation mast

The starting point for this case is a situation with LH2 leakage in the TCS. The cold gas formed must be vented out of the TCS to avoid build-up of pressure and H2-concentration. Testing of releases of cold hydrogen gas emissions from the ventilation mast from the TCS should therefore be seen in context with LH2 leakage in the TCS. If possible, it is therefore preferable to do as much as possible of the ventilation mast testing during the testing of “LH2 Closed-room Leakage (TCS)

There are some uncertainties regarding the fate and consequences of the gas emitted from the ventilation mast. Emissions of cold H_2 gas from the vent mast should be tested, in combination with testing of LH_2 leakage in closed room. The following parameters should be measured and recorded:

- The spread of cold H_2 gas, especially downwards, from the ventilation mast
- Possible solidification of O_2 in the atmosphere in form of “O_2-snow”
- Cases of blocking of the ventilation mast due to solidification of gasses and moisture in the atmosphere
- Case of blocking of the ventilation mast with the presence of N2 (inerting) in TCS.