Pre-normative REsearch for Safe use of Liquid HYdrogen (PRESLHY)

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

Grant Agreement Number 779613

Deliverable Number:	
Title:	WP2 Consequence Analysis
Authors:	Simon Jallais, Laurence Bernard
Submitted Date:	19/12/2018
Due Date:	15/04/2019
Report Classification:	Confidential

Deliverable	
Contractual delivery date	
Actual delivery date	
Deliverable Number	
Deliverable Name	
Internal document ID	D2.X
Nature	Report

Approvals			
	Name	Organisation	Date
WP Leader	Jallais Simon	Air Liquide	
Coordinator			

Disclaimer

Despite the care that was taken while preparing this document the following disclaimer applies: The information in this document is provided as is and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof employs the information at his/her sole risk and liability.

The document reflects only the authors' views. The FCH 2 JU and the European Union are not liable for any use that may be made of the information contained therein.

Publishable summary

Key words

Consequence analysis, LH_2, modelling.

Abbreviations

GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GO_2	Gaseous Oxygen
H_2O	Water
LFL	Lower Flammability Limit
LH_2	Liquid Hydrogen
LN_2	Liquid Nitrogen
LO_2	Liquid Oxygen
MIE	Minimum Ignition Energy
NRT	Non-Reversible effects Threshold
PSV	Pressure Safety Valve
1%T	1% lethality threshold
5%T	5% lethality threshold

Table of Contents

Abbreviations 4

Description of the Liquid Hydrogen refueling station 6

Scenarios 7

Modelling Assumptions 8

Results 9

Modelling results 9

1. Description of the Liquid Hydrogen refueling station

Basically the LH_2-based fueling station under consideration consists in :

- An horizontal LH_2 tank ($22 m^3$ - 1098 kg). The maximal operating pressure is 10.3 bara;
- an insulated process line from the bottom of the storage to the LH_2 pump, driving LH_2 from the storage tank to a vaporizer. This device allows to pump LH_2 up to 1000 bar;
- a heater (named VAP : hot oil, electric in order to heat up hydrogen at 1000 bar);
- A 1000 bar gaseous buffer (few m^3). These buffers are generally bundles of type I or II metallic cylinders or long metallic tube.

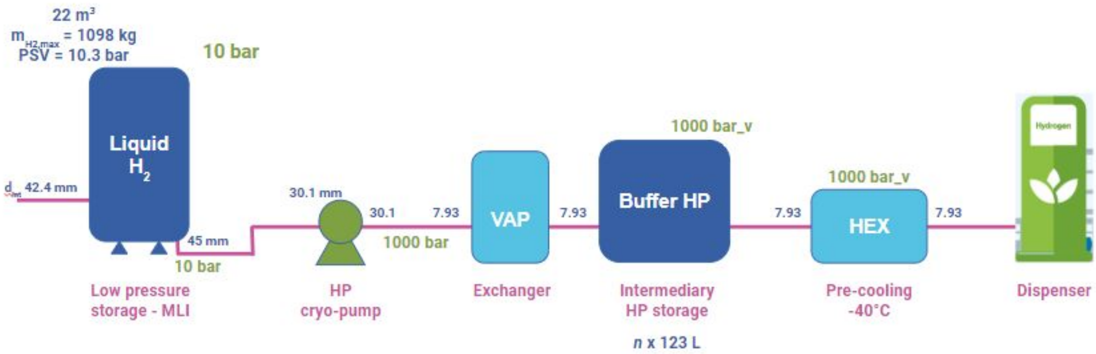

Figure 1: Model of a liquid hydrogen refuelling station.

All the other parts (dispenser, filling hose, …) of the refueling station are similar to classical gaseous refueling station.

The LH_2 tank is delivered by a LH_2 truck. This LH_2 truck is composed of a 40 m^3 horizontal tank operating between 1 and 12 bar (inventory : 4t). The connection between the storage and the truck is done by a flexible transfer line. The transfer is performed without a pump. A small vaporizer is present on the trailer to produce a pressure build-up in the truck tank and allow the transfer of liquid H_2 in the stationary vertical storage.

2. Scenarios

The following scenarios are suggested :

Scenario 1 : Vessel burst at P<P(PSV)
The first scenario considered is a vessel burst for a pressure inferior to the pressure relief valve limit, due to flying fragments or a storage mechanical failure. The total quantity of H_2 released is the inventory of the LH_2 tank namely 1098 kg. It corresponds to a filling level of 90% in LH_2. The hydrogen is at 8 bar pressure and saturated conditions. The release is considered instantaneous. We consider the vessel to unzip along its full diameter with a horizontal release.

Scenario 2 : Vessel burst at P>P(PSV)
The second scenario considered is a vessel burst for a pressure superior to the pressure relief valve limit, due to an exposure to a fire or to a failure of the PSV. The release is considered instantaneous. The hydrogen is at 15 bara and supercritical conditions. The total quantity of H_2 released is the inventory of the LH_2 tank namely 1098 kg. It corresponds to a filling level of 90% in LH_2.

Scenario 3 : Pipe full bore rupture before the pump
The third scenario considered is a full bore rupture between the LH_2 storage tank and the pump. The total quantity of fuel released is 1098 kg of H_2 saturated at 8 bar through a 45 mm diameter pipe.

Scenario 4 : Pipe partial rupture before the pump

The fourth scenario considered is a partial rupture of the pipe between the LH_2 storage tank and the pump. The total quantity of fuel released is 1098 kg of H_2 saturated at 8 bar through an 8 mm diameter hole.

Scenario 5 : Pipe full bore rupture after the pump
The fifth scenario considered is a pipe rupture between the pump and the vaporizer. The H_2 is released in supercritical state at 1000 bar through a 30.1 mm diameter pipe. The leak rate is determined by the pump rate of 50 kg/h.

Scenario 6 : Partial pipe rupture after the pump
The sixth scenario considered is a partial rupture of the pipe between the pump and the vaporizer. The H_2 is released in supercritical state at 1000 bar through a 5.2 mm diameter hole. The leak rate is determined by the pump rate of 50 kg/h.

Scenario	H_2 quantity released	Pressure (bara) Temperature (K)	Release duration	Release diameter (mm)	Discharge rate (kg/s)
1	1098 kg	8 bara saturated	Considered instantaneous	na	na
2	1098 kg	15 bara supercritical	Considered instantaneous	na	na
3	1098 kg	8 bara saturated	To be calculated	45	To be calculated
4	1098 kg	8 bara saturated	To be calculated	8	To be calculated
5	na	1000 bar supercritical	To be calculated	30.1	To be calculated
6	na	1000 bar supercritical	To be calculated	5.2	To be calculated

Figure 2: Summary of scenario conditions.

The frequencies of these scenarios will be evaluated later.

3. Modelling Assumptions

The main assumptions are as follows :

- The source of emission is fixed in space,
- The dimensions of the storage are 4m long, 2.5m diameter;
- Even in case of tank or pipe blowdown (variable outflow), the conservative initial flow is considered. We consider a 2m long pipe for the different scenarios (if needed);
- To simplify, the wind may be not considered,
- If the modeler wants/needs to consider wind, conditions 3F and 5D are preferred. The height of the release is 10m. The wind has the same direction as the release.

The French thresholds are considered ("arrété" of the 29th of September 2005).

For instance for radiative heat flux, these thresholds are considered :

- 3 kW/m² for the non-reversible effects threshold (NRT),
- 5 kW/m² for the 1% lethality threshold (1%T),
- 8 kW/m² for the 5% lethality threshold (5%T).

Hazards	Consequences	Unit	NRT	1%T	5%T
Jet flame	Radiative heat flux	kW/m^2	3	5	8
Jet flame	Thermal Dose	$(kW/m^2)^{4/3}.s$	600	1000	1800
Delayed explosion	Overpressure	mbar	50	140	200
Delayed explosion	Temperature effects	-	110% of the burning zone	100% of the burning zone	100% of the burning zone

Figure 3: French thresholds for radiative heat flux, thermal dose and overpressure.

If the duration of the phenomena is longer than 120 sec, radiative heat flux must be considered.

4. Results

5. Modelling results

5.1. Air Liquide

5.1.1. Scenario 1

Scenario 1	Distance to		
Model description:	NRT	1%T	5%T
If scenario not performed, why?:			

5.1.2. Scenario 2

Scenario 2	Distance to		
Model description:	NRT	1%T	5%T
If scenario not performed, why?:			

5.1.3. Scenario 3

Scenario 3	Distance to		
Model description:	NRT	1%T	5%T
If scenario not performed, why?:			

5.1.4. Scenario 4

Scenario 4	Distance to		
Model description:	NRT	1%T	5%T
If scenario not performed, why?:			

5.1.5. Scenario 5

Scenario 5	Distance to		
Model description:	NRT	1%T	5%T

If scenario not performed, why?:			

5.1.6. Scenario 6

Scenario 6	Distance to		
Model description:	NRT	1%T	5%T
If scenario not performed, why?:			

5.2. KIT

5.3. NCSRD

5.4. ….

5.5.