HYDROGEN VENT SYSTEMS FOR CUSTOMER APPLICATIONS

Doc 211/24

Revision of Doc 211/17

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Amendments to 211/17

Section	Change
3.2	Definitions revised
4.3	Paragraphs deleted
5.3	New paragraphs added
8	Paragraphs deleted

NOTE Technical changes from the previous edition are marked on the left

1 Introduction

The purpose of this publication is to provide recommendations and a methodology for the safe design of venting systems for hydrogen installations and equipment located at a customer site.

The design of a hydrogen vent system aims at preventing Deflagration to Detonation Transition (DDT) and mitigating the hazards from fires, deflagration and DDT if it occurs. The following scenarios are reflected:

- deflagration due to the delayed ignition of the explosive hydrogen/air mixture coming out of the vent stack;
- thermal radiation generated by the jet fire (the flame coming out of the vent stack); and
- DDT inside the vent system due to the acceleration of the combustion of the air/hydrogen mixture that can be present inside the venting system (in the presence of an ignition source). This hazard is relevant if air can enter the venting system.

2 Scope

This publication covers the design, installation and maintenance of hydrogen vent systems used for equipment located at a customer site. This publication is not applicable to vent systems of hydrogen installations with capacity exceeding 5000 Nm3/hr of hydrogen.

It applies to Hydrogen Refuelling Stations with standard supplies of hydrogen (liquid, gas bulk, gas cylinders, on-site production of less than 5000 Nm3/hr of hydrogen).

Typical on-customer-site installations to which this document refers include equipment items such as:

- A fixed or transportable gaseous storage connected to a piping distribution network at low or high pressure through a gas pressure release system;
- A fixed or transportable liquid storage connected to a piping distribution network at low or high pressure through a pump / vaporizer;
- A gaseous compressor to increase hydrogen pressure up to 1000 bar;
- A high pressure hydrogen storage up to 1000 bar;
- One or more hydrogen dispensing systems to fuel hydrogen powered vehicles; and
- Stationary fuel cells systems.

Vent systems on vehicles themselves are excluded from the scope.

The vent system can be part of a gaseous or liquid hydrogen system. The scope is

a) from the discharge of the device(s) controlling the release of hydrogen to the vent exit(s) to atmosphere. The piping up to inlet of the venting control device is also within scope as well as the silencer if any.
b) up to the point where hydrogen concentration in the atmosphere is at the lower flammable limit.

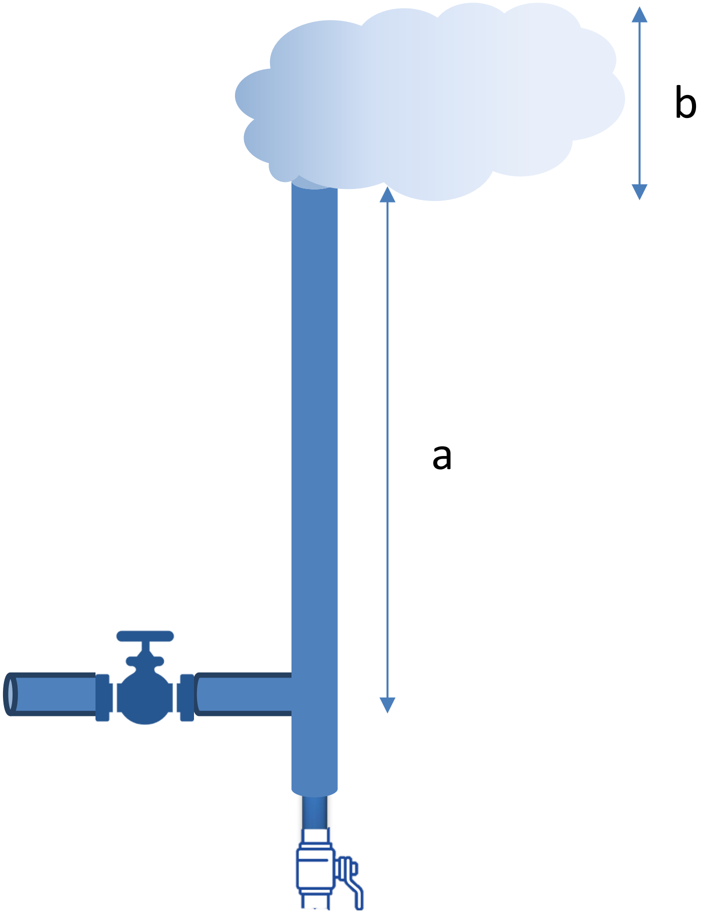


Figure 1: Scope of a vent system: a) vent system piping scope including stack b) flammable cloud

This publication does not cover:

- The design of the devices controlling the release of hydrogen;
- Flare systems; or
- Inerted vent systems.

3 Definitions

For the purpose of this publication, the following definitions apply:

3.1 Publications terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May and need not

Indicate that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

For the purpose of this publication, the following definitions apply:

3.2.1 Vent system

A vent system is the apparatus used for depressurizing or relieving gas from a system to a safe location. Vents can be used for normal discharge, abnormal discharge or emergency discharge as required. The vent stack is the part of the vent system routing the gas to the designed elevation with an outlet to direct the flow.

3.2.2 Pressure relief device (PRD)

A safety device used to control or limit the pressure in a system.

3.2.3 Deflagration in a flammable vapour cloud

Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

3.2.4 Detonation in a flammable vapor cloud

Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium.

4 Sizing of a vent system

4.1 Definition

For gaseous hydrogen supply systems, the following are examples of releases:

- Manual venting;
- Purging;
- Venting of upstream compressor or cryogenic pump flow feeding the system; and
- In fuelling stations, malfunction of dispensing control valve causing filling line safety pressure valve to open.

For liquid hydrogen supply systems, the following are examples of releases:

- Manual venting;
- Purging;
- Normal boil-off from ambient heat input;
- Liquid flash and gas displacement during filling of the tank;
- Gas returned from cool down of lines, pumps and connected equipment; and

- Boil-off following loss of vacuum on a tank or on vacuum insulated lines.

The following event is not considered in this guideline for sizing the vent system:

- Catastrophic events as general fire; and

These events should be considered in the risk assessment of the installation to define the likelihood of the event, the corresponding harm effects to people and goods and the appropriate mitigation measures to be implemented: design and layout requirements, standard operating procedures, and emergency procedures.

4.2 Maximum flow rate and maximum pressure drop calculation

The maximum flow rate shall be calculated as the sum of the flow rates of hydrogen collected in the vent system coming from all devices that could be simultaneously opened. It corresponds to the highest flow rate generated by upset conditions in the worst credible conditions.

The sum of design flows of all vent devices which can open at the same time into the common vent system results in a maximum pressure drop.

The maximum pressure drop shall be taken into account for choosing the pressure relief device and defining the set pressure.

This maximum pressure drop should generally not exceed 10% of the lowest set pressure of all the relief valves which can open at the same time, and shall not exceed the maximum back pressure specified for any of these relief valves.

The pressure loss in the line between the protected equipment and a pressure relief device shall not exceed 3 % of the relief device set pressure.

NOTE Excessive backpressure can result in relief valve "chatter", i.e. flow instability, greatly reducing the average flow and a potential source of damage to the relief valve.

4.3 Piping diameter and exit velocity

Hydrogen-air mixtures can exist in the vent system at concentrations within the flammable range. This can lead to a deflagration or detonation of the hydrogen-air mixture inside the vent system, which is typically indicated by an audible pop coming from the vent stack. This is an event that shall be considered in the vent system design maximum allowable design pressure. This typically occurs when the hydrogen flow initially starts and before the residual air has been purged from the vent piping.

The principal measure for the potential of deflagration or detonation inside the vent system and piping is the ratio of length to internal diameter (L/D) of the components. Generally, the greater the L/D ratio, the greater the probability of these occurrences. In case the intrinsically safe design cannot be made every effort shall be made to reduce this ratio to the lowest level practical. When the L/D ratio exceeds 100:1, the chance for detonation increases. [6]

The vent piping diameter shall not be less than the diameter of any pressure-relief valve outlet, and large enough to avoid exceeding the maximum allowable pressure drop specified in 4.2.

For hydrogen, vertical venting, upward discharge is the preferred option, the higher the discharge velocity the smaller the separation distance requirements around the vent as specified in 7.1.

The sound level should comply with local regulation for normal or abnormal releases.

NOTE: Many local regulations permit to exceed the sound level limits in case of transient and/or abnormal or emergency conditions like, for example, the opening of a safety valve.

5 Structural design

5.1 Environmental loads

Seismic loading shall be considered for self-supported vent systems.

Potential environmental loads shall be taken into consideration for the mechanical design of the venting systems, such as wind load, snow or ice accumulation as well as possible flooding.

5.2 Design pressure

Piping and connections immediately downstream of non-reclosing pressure relief devices, for example a burst disk, shall be designed to withstand the transient pressure peak generated upon activation.

Burst pressure of vent piping shall meet requirements of 5.5 to prevent damage from deflagration or detonation.

5.3 Thrust resilience

The vent system shall be designed to restrain the thrust of the reaction forces resulting from full-flow discharge of fluid under any operating or failure condition. To prevent deflection or damage to the vent system support and bracing of the piping shall be designed to compensate for the reaction forces and given allowance for generation of shock waves.

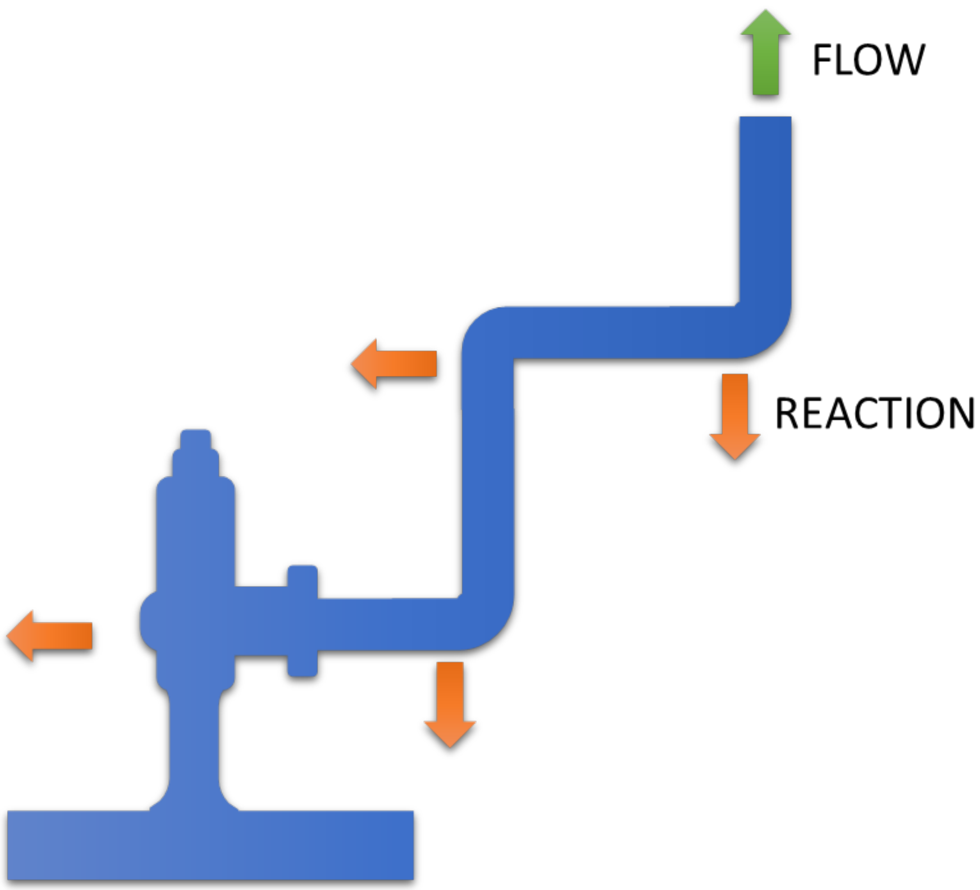


Figure 2: Reaction forces from discharge of gas

5.4 Piping and Fittings

Austenitic stainless steel equivalent to grade 304 or 316 show good resistance to corrosion and fire conditions and therefore can be used for the vent piping system and the silencer.

Hydrogen embrittlement is not expected considering the operational conditions of the vent system.

Vent piping should be routed and configured to minimize back pressure.

The length of the piping upstream of safety devices should be minimized.

5.5 Resistance to overpressure generated by ignition of an internal hydrogen/air mixture

The vent system shall be able to withstand the maximum peak pressure created by a detonation except if inert gas is used for continuous purging and so avoiding presence of oxygen within the vent system.

- Detonation pressure will increase with length and complexity of the vent system. Dynamic pressure values can reach up to 120 bar peak for complex systems.
- Failure of the vent system from overpressure could present a potential hazard to personnel and equipment in the vicinity.

Burst pressure shall be such that the pipe system will not rupture as a result of the overpressure that could be generated inside the piping by the ignition of a flammable hydrogen air mixture possibly present in the system.

Each company may use the method of its choice to calculate the pipe wall thickness.

- The vent system typical minimum design pressure shall be 40 bar. A pipe designed for 40 bar static load will be able to cope with significant higher dynamic pressure.
- In order to define the minimum thickness for vent pipes up to DN100 to withstand the overpressures described previously, the following table can be used for carbon or stainless steel pipes.

Table 1: Minimum thickness for vent pipes

	1 inch or DN25	2 inch or DN50	3 inch or DN80	4 inch or DN100
Minimum pipe thickness in mm	0,69	1,25	1,84	2,37
NOTE: The recommendations in this table have been developed based on the method described in NFPA 67 *Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems* [1][1] with the addition of a safety factor for the recognized peak overpressure that can exceed the steady state detonation effect described.				

6 Vent Silencers

When a silencer is put in place, the cross-sectional area of the tail pipe located at the outlet of the vent stack shall not be less than the available free flow through the cross section of the silencer.

Silencers shall be provided with drains to prevent accumulation of water in the system.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

7 Functional design

7.1 Vent exit design, prevention of water ingress, water purging

Outlet shall be vertical upwards (preferred option) or an angled outlet (0° to 90° from vertical) directed upwards can be used in specific cases.

The potential ingress and accumulation of water, snow, and/or debris that can affect the active system components by corrosion, blockage, or ice should also be considered in the risk assessment.

Non-horizontal vent exits should be designed to limit rain ingress.

Vent systems with a non-horizontal outlet shall be equipped with a water drain at the bottom of the vent system.

7.2 Prevention of blockages from animals or insects / debris protection

Hydrogen vent systems should be protected against the hazards caused by entering of debris and/or insects inside the vent pipes resulting in potential obstruction / clogging.

Use of vent protectors equipped with wire screens is possible, e.g. Mud Dauber fittings, provided the proper mesh size is selected to avoid flow obstruction.

7.3 Grounding / electrical continuity

Hydrogen vent piping and associated valves/devices/systems shall be electrically grounded and bonded as required by IEC 60204-1 *Safety of machinery - Electrical equipment of machines - Part 1: General requirements* [2] to give protection against the hazards of the development of electrical charges, stray electrical currents, static electricity and lightning.

For grounding various values for maximum resistance exist in the literature. They include:

- IEC 30204-1 refers to 100 Ohm
- EIGA Doc 250 “Standard procedures for Hydrogen supply systems” refers to 25 Ohm.
- CGA 5.5 "Hydrogen venting” refers to 25 Ohm.
- NEC 250.56 refers to 25 Ohm.
- NFPA 70 refers to 25 Ohm.

7.4 No flame arrestor

Vent lines shall not be fitted with flame arrestors as this may cause a restriction that prevents the free release of hydrogen to the atmosphere.

8 Exposure criteria

8.1 Heat radiation criteria

Heat radiation criteria are given as heat flux in W/m^2 for continuous exposure or in thermal dose $(kW/m^2)^{4/3}s$ (Thermal Dose Unit TDU) for a defined exposure time.

The Eisenberg method to define the hazard zone uses the radiation dose approach. This considers that the effect of radiant heat on humans is a function of both radiation intensity and duration of exposure. Eisenberg et al. (see EIGA Doc 121 *Hydrogen pipeline systems* [3]) studied data on the lethality from thermal radiation and concluded that the dosage-response is in relationship for various probabilities of injury/fatality should be in the form of,

$D = t\, \mathbf{I}^{4/3}$ in units of $(kW/m^2)^{4/3}s$

where:

D = dosage for various probability of injury

t = duration of the exposure, sec

I = thermal radiation intensity, kW/m^2

For short duration exposure (up to 45 s), the following thermal dose criteria may be applied:

Table 2: Thermal dose

Thermal Dose	Harm to people
85 - 127 $(kW/m^2)^{4/3}s$	Pain
290 $(kW/m^2)^{4/3}s$	Second degree burn
600 $(kW/m^2)^{4/3}s$	Irreversible effects threshold
1000 $(kW/m^2)^{4/3}s$	Lethal effects threshold
1800 $(kW/m^2)^{4/3}s$	Significant lethal effects threshold (50 % of fatality)

For longer duration exposure, the following thermal flux values may be used [2]:

[2] The values include the solar radiation effect.

Table 3: Thermal flux

Thermal flux	Harm to people
1,58 kW/m^2	Maximum radiant heat intensity at any location where personnel with appropriate clothing can be continuously exposed.
2,9 kW/m^2	Time to pain threshold for 30 seconds.
3 kW/m^2	Irreversible effects threshold. For public for all cases except for very rare accidental releases.
4,73 kW/m^2	Maximum radiant heat intensity in areas where emergency actions lasting 2 min to 3 min can be required by personnel without shielding but with appropriate clothing.
5 kW/m^2	Lethal effects threshold.
6,31 kW/m^2	Maximum radiant heat intensity in areas where emergency actions lasting up to 30 s can be required by personnel without shielding but with appropriate clothing.
8 kW/m^2	Significant lethal effects threshold (5% of fatality).
9,46 kW/m^2	Maximum radiant heat intensity at any location where urgent emergency action by personnel is required. When personnel enter or work in an area with the potential for radiant heat intensity greater than 6,31 kW/m^2, then radiation shielding and/or special protective apparel (e.g. fire approach suit) should be considered.

Solar radiation and wind influence the thermal effects on persons and should be taken into consideration separately or included in the threshold values.

There are other methodologies to calculate heat radiation, as described in Doc 75 Separation distances.

8.2 Specific Areas

Harm criteria could be adapted to the level of protection of people and buildings. A way to classify areas is the following:

- Public area;
    - People have unrestricted access and have no particular protection;
- Areas of parking or access to administrative buildings;
    - Area is restricted to employees and visitors. People are normally mobile and can react to events;
- Areas with restricted access;
    - Area is restricted to qualified and trained people, who have appropriate personal protection equipment PPE (e.g. flame retardant clothing FRC, personal gas detectors).

9 Location of outlet

9.1 Safe location

Flows from vents and safety relief equipment shall be piped outdoors to a safe location where they do not generate a hazard for persons or neighbouring structures, away from personnel areas, electrical lines and other ignition sources, air intakes, building openings and overhangs.

9.1.1 Lightning protection

In general hydrogen vents do not require lighting protection, as vent lines are designed to withstand the consequences of an ignition.

9.2 Separation distances

9.2.1 Criteria on heat radiation, hydrogen concentration, overpressure

The vent outlet location (height; distance to exposures) should be such that the limits defined for each area are not exceeded under any foreseeable venting situation.

The vent location should be calculated using thermal flux or thermal doses at a height of 1,8 m.

a) Maximum hydrogen concentrations should be <4% hydrogen in air (by volume):

- at windows and openings
- in areas where persons or personnel can be present

For air intakes the concentration threshold should be 2% hydrogen in air (by volume) or lower.

b) Maximum thermal radiation or thermal dose.

The heat radiation criteria defined at 8.3 may be used to define the separation distances. Different criteria may be selected depending on the access categories.

As an example, higher heat flux and/or thermal dose may be applied for restricted areas than for public areas.

c) Maximum overpressure effects criteria in case of delayed ignition may be applied.

Table 4: Overpressure effects

Item subject to overpressure	Threshold
Windows (non-reinforced)	<20mbar
Areas with or without restriction of access or walkway	<100 mbar (persons)
Buildings (non-reinforced)	<50 mbar

-

10 Hazardous area classification and safety distances

Zone classification according to ATEX is summarized in EIGA Doc 134 *Potentially explosive atmospheres EU directive 1999/92/EC* [4].

Safety distances may be calculated using dispersion calculation. The tables in Appendix 1 shows examples of calculations of horizontal distances for different flow rates, vent diameters and inclination from 2017 using Phast software:

- to reach a given thermal flux (3, 5 or 8 kW/m^2);

- to reach LFL (4% hydrogen in air by volume);
- at a height of 1,8m.

11 Venting of cold hydrogen

11.1 Hydrogen vent sources

Cryogenic and non-cryogenic hydrogen shall be vented through separate venting systems. This is to ensure the piping material is selected correctly (see 11.2), air condensation is taken into account (see 11.6) and dispersion is calculated correctly.

11.2 Material

In addition to general prescriptions, the material used in vents of cold hydrogen shall be suitable for low temperatures (cold embrittlement).

11.3 Thermal contraction

Thermal contraction shall be accounted for.

11.4 Prevention of blockage by freezing water

Build-up of ice at the point of release shall be prevented.

Releases of cryogenic hydrogen allowing build-up of ice at the point of release shall be avoided.

Horizontal piping allowing ice to grow to point of release shall be avoided – see CGA G-5.4 *Standard for Hydrogen Piping Systems at User Locations* [5].

Particular attention shall be given to avoid water accumulation in the vent piping through regular activation of the water drain device.

11.5 Vaporization prior to release

Venting systems shall be designed to ensure vaporization of normal discharges of liquid hydrogen before release to atmosphere.

Vent piping of cryogenic hydrogen shall not be thermally insulated.

11.6 Condensation of air

Means shall be provided to minimise exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members and surfaces not suitable for cryogenic temperatures.

Cryogenic hydrogen venting may lead to condensing air and potential formation of an oxygen enriched atmosphere. Uninsulated piping and equipment, which operates at below air condensation temperature, shall not be installed above asphalt surfaces or other combustible materials in order to prevent contact of liquid air with such materials. For the purposes of this standard, asphalt and bitumen paving shall be considered combustible. If expansion joints are used, fillers shall also be made of non-combustible materials. Drip pans may be installed under uninsulated piping and equipment to retain and vaporise condensed liquid air.

11.7 Protection of personnel

Exposure of personnel and equipment to falling ice from piping and vent tips shall be avoided.

12 Inspection and maintenance

12.1 Inspection

A visual inspection should be performed periodically and cover the following:

- the mechanical integrity of the support system
- determine that the vent system discharge is free from potential obstructions such as bird nests, insect hives, vegetation, etc.
-

If the vent system is equipped with a water drain device (sump) at the bottom of vent stack, it should be periodically checked to prevent accumulation of moisture or ice.

The vent system valves shall be checked on a periodic basis to ensure proper operational functions.

12.2 Field maintenance and repair

Only qualified and trained service technicians shall carry out any repairs to the vent system.

All sources of hydrogen that are piped to a vent system shall be considered before the repair of any component and be disconnected or piped to a temporary vent system if appropriate. Personnel shall be aware of any releases that can occur while repairing a vent system.

Presence of a hydrogen-rich atmosphere within the vent system shall be assumed. Before and during any type of repair work, an inert gas purge shall be performed.

Personnel shall be alert and aware of the risk of ignition of the hydrogen released.

During any type of work on a liquid hydrogen system, personnel shall be aware of the extremely low temperature and its associated hazards.

12.3 Ignition at outlet

Occasional ignition at vent outlet is expectable and should not be considered abnormal. In case of an ignition, it shall not be attempted to extinguish the flame by spraying water at the vent stack. The source of hydrogen should be isolated if appropriate.

13 References

Unless otherwise specified, the latest edition shall apply.

[1] NFPA 67, *Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems*, National Fire Protection Association. www.nfpa.org

[2] IEC 60204-1 *Safety of machinery - Electrical equipment of machines - Part 1: General requirements*. International Electrotechnical Commission. www.iec.ch .

[3] EIGA Doc 121 *Hydrogen Pipeline Systems.* www.eiga.eu

[4] EIGA Doc 134 *Potentially Explosive Atmospheres EU Directive 1999/92/EC*. www.eiga.eu

[5] CGA G-5.4 *Standard for Hydrogen Piping Systems at User Locations*. Compressed Gas Association. www.cganet.com

[6] CGA G-5.5 *Standard for Hydrogen Vent Systems*. Compressed Gas Association. www.cganet.com

14 Additional References

EIGA Doc 06 *Safety in Storage, Handling and Distribution of Liquid Hydrogen.* www.eiga.eu

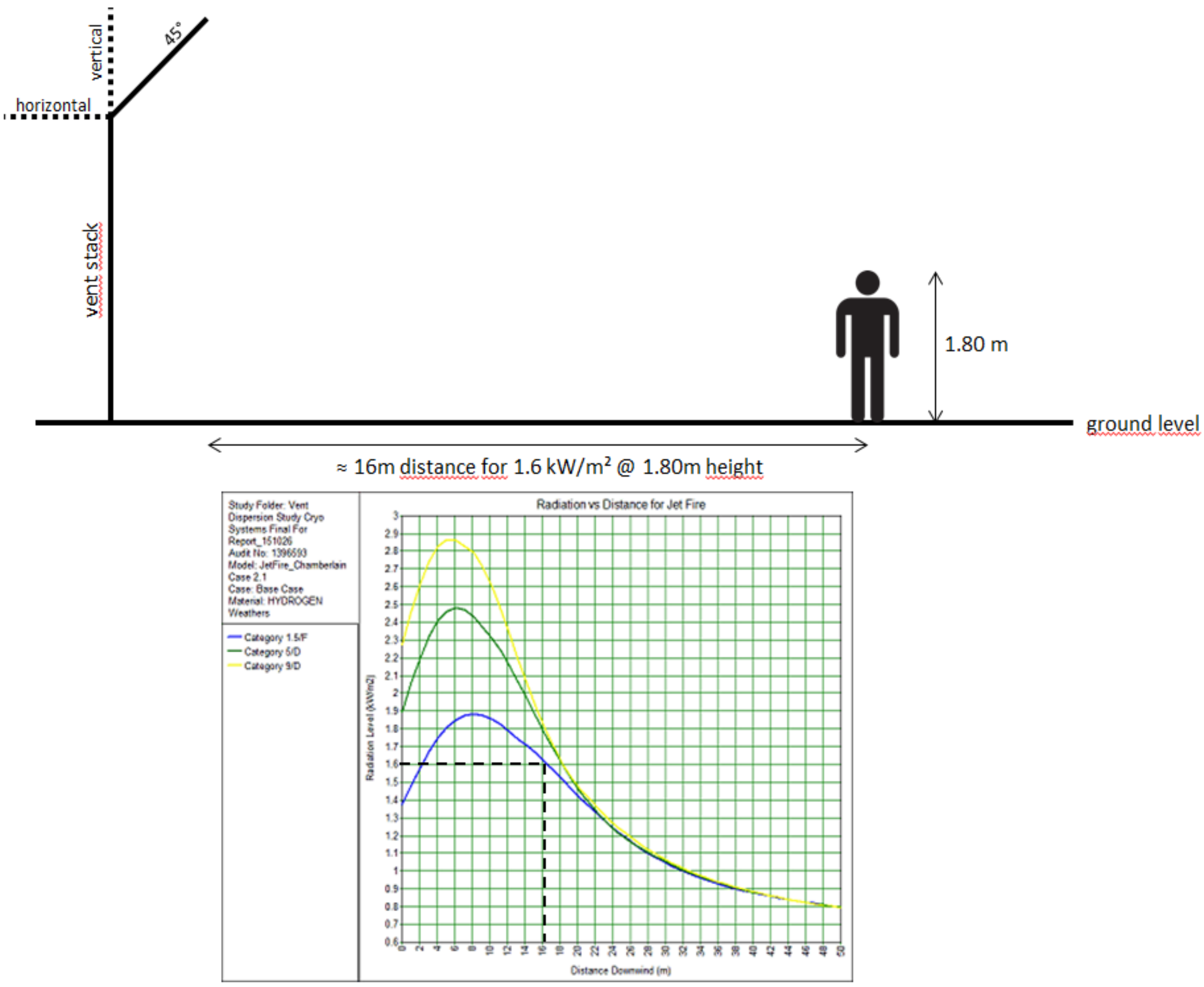
EIGA Doc 15 *Gaseous Hydrogen Stations.* www.eiga.eu

Appendix 1: Hydrogen vent modelling – Horizontal distance (2017 calculations)

Input Data

Flow Rate [Nm³/h]	Mass Flow Rate [kg/h]	Release Velocity [m/s]			Mass Flow Rate [kg/s]
		DN50	DN100	DN 25	
100	8,9	14,1	3,5	56,6	0,002480159
500	44,6	70,7	17,7	282,9	0,012400794
1000	89,3	141,5	35,4	565,9	0,024801587
2500	223,2	353,7	88,4	1414,7	0,062003968
5000	446,4	707,4	176,8	2829,4	0,124007937

Release velocity is limited to 500 m/s as per Phast program
Vent height 5 m
LFL Calculation Height = 1,8 m



Results distance to specific heat radiation (in 1,8 m height) – Vertical vent inclination

Weather 3/F

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5000	n/a	n/a	n/a	n/a	n/a	n/a	4	n/a	n/a

Weather 5/D

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	6.2	n/a	n/a
5000	n/a	n/a	n/a	n/a	n/a	n/a	7,8	n/a	n/a

Weather 9/D

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	2,45	n/a	n/a	4,2	n/a	n/a
2500	n/a	n/a	n/a	3,2	n/a	n/a	7,1	5	n/a
5000	5,8	n/a	n/a	5,9	n/a	n/a	9,3	6,9	n/a

Results distance to specific heat radiation (in 1,8 m Height) – 45° vent inclination

Weather 3/F

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5000	7,5	n/a	n/a	7,6	n/a	n/a	10	n/a	n/a

Weather 5/D

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	3,6	n/a	n/a	5,1	n/a	n/a	7,4	n/a	n/a
5000	8,2	n/a	n/a	8,2	n/a	n/a	10,2	6,3	n/a

Weather 9/D

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	3,5	n/a	n/a	4,4	n/a	n/a
2500	5,1	n/a	n/a	5,8	n/a	n/a	7,6	n/a	n/a
5000	8,2	5,4	n/a	8,2	5,5	n/a	11	5	n/a

Results distance to specific heat radiation (in 1,8 m Height) – 90° vent inclination

Weather 3/F

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	3,5	n/a	n/a	4,5	n/a	n/a
1000	4	n/a	n/a	6,7	4,3	n/a	8,1	5,9	n/a
2500	9	5,1	n/a	9,9	8,1	6	12,6	10,7	8,6
5000	13,2	11,3	9,5	13,2	11,3	9,5	16,3	14	12,5

Weather 5/D

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	3,1	n/a	n/a	4	n/a	n/a
1000	3,4	n/a	n/a	6,2	3,7	n/a	7,4	5,2	n/a
2500	8,2	6,6	4,2	9,1	7,3	5,3	11,7	10	7,8
5000	12,2	10,5	8,8	12,2	10,5	8,8	15,1	13	11,5

Weather 9/D

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	2,8	n/a	n/a	3,7	n/a	n/a
1000	3,1	n/a	n/a	5,8	3,5	n/a	7	4,6	n/a
2500	7,8	6,2	4	8,7	7	5	11,1	9,3	7
5000	11,6	9,7	8,3	11,6	9,7	8,3	14,5	12	10,8

n/a not applicable

All results are based on Cone Model with Chamberlain correlation.

For 90° inclined (horizontal) release: horizontal jet fire option as per Phast recommendation has not been used because resulting heat radiation was lower than for vertical and 45° inclined releases (seems not to be reasonable).

The height for calculation of flammable effects is 1,8 m; calculation of the LFL contour at ground level.

Results extension LFL

Weather 3/F

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,1	1,4	1,5	1,41	1,5	1,5	2	1,7	1,6
500	1,1	1,8	2,2	2,3	2,5	2,5	4	3,5	2,9
1000	1,1	2	2,6	2,9	3,2	3,2	5,4	4,9	3,9
2500	1,7	2	3,2	4,4	4,4	4,6	7,7	7,6	6,2
5000	2,2	2,3	3,5	5,8	5,9	6,1	10,2	10,2	8,9

Vent height

Weather 5/D

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,2	1,6	1,8	1,47	1,7	1,8	2	2	1,9
500	1,2	2,1	2,7	2,1	2,6	2,9	3,7	3,5	3,3
1000	1,2	2,3	3,1	2,5	3,2	3,5	4,8	4,7	4,2
2500	1,9	2,3	3,7	3,8	4	4,7	6,7	6,7	6,2
5000	2,6	2,6	4	5,1	5,2	5,8	8,9	8,9	8,3

Weather 9/D

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,2	1,6	1,7	1,38	1,7	1,7	1,9	1,9	1,8
500	1,3	2,1	2,6	1,9	2,5	2,8	3,2	3,2	3,1
1000	1,3	2,3	3,1	2,2	2,9	3,4	4	4,1	4
2500	2	2,4	3,7	3,3	3,6	4,4	5,7	5,7	5,6
5000	2,7	2,8	4,1	4,5	4,6	5,3	7,4	7,4	7,2