FIRE PREVENTION TECHNICAL RULE FOR GASEOUS HYDROGEN TRANSPORT IN PIPELINES

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ABSTRACT

This paper presents the current results of the theoretical and experimental activity carried out by the Italian Working Group on the fire prevention safety issues in the field of the hydrogen transport in pipelines. From the theoretical point of view a draft document has been produced beginning from the regulations in force on the natural gas pipelines; these have been reviewed, corrected and integrated with the instructions suitable to the use with hydrogen gas. From the experimental point of view a suitable apparatus has been designed and installed at the University of Pisa; this apparatus will allow the simulation of hydrogen releases from a pipeline with or without ignition of the hydrogen-air mixture. The experimental data will help the completion of the above-mentioned draft document with the instructions about the safety distances. However, in the opinion of the Group, the work on the text contents is concluded and the document is ready to be discussed with the Italian stakeholders involved in the hydrogen applications.

NOMENCLATURE

A.R.S.: Automatic Release System

H.P.B.T.: Hydrogen Pipe Break Test

D.M.: Decreto Ministeriale (Ministerial Decree)

1.0 INTRODUCTION

Pipelines are one of the options taken into consideration in order to transport hydrogen to the users. The hydrogen pipe network is worldwide very limited (about 740 km in the U.S.A., 1500 km in Europe); it is mainly intended to deliver hydrogen from the producers directly to the consumer sites or to large industrial areas such as oil refineries or chemical plants. Further but small-sized networks are used internally by the hydrogen producers themselves. On the contrary, the Authors do not still know examples of hydrogen pipelines used for civil purposes.

The lack of specific rules also persists in the field of the hydrogen pipelines. In Italy there is a lot of experience in the field of the natural gas transport in pipelines; therefore some national producing companies install their own hydrogen pipelines with reference to the requirements for the natural gas pipelines. However, this often involves hydrogen installations complying with different safety strategies and objectives. Furthermore, the unique physical and chemical properties of the hydrogen require specific and additional measures, e.g. the choice of suitable materials in order to avoid hydrogen embrittlement. These issues are even more important for civil installations where the burden of the safety mainly falls on the right design, construction and installation of a system.

The Italian Working Group on the fire prevention safety issues [1] has considered the hydrogen transport in pipelines the main topic to be regulated after the work it has performed on the regulation of the hydrogen refuelling stations (Decree issued) [2] and the hydrogen vehicle components [3]. The Group has produced a specific draft of technical rule; this is intended to help the installation of hydrogen pipelines with the use of well-defined minimum safety standards and without high disadvantages for this technology. This paper analyzes this technical rule and explains the criteria used herein.

In order to better assess the specific behaviour characterizing the hydrogen releases from a pipeline, the Group has decided to support its theoretical work with a suitable experimental activity. For this purpose, a proper apparatus has been installed at the University of Pisa, Department of Mechanical, Nuclear and Production Engineering: this apparatus is named H.P.B.T. (Hydrogen Pipe Break Test) and will allow an experimental campaign aimed at studying the hydrogen release and ignition in the event of hydrogen flow at a pressure up to 1 MPa and with a release period from 0 to 240 s. This experimental activity will also provide useful information in order to validate the calculation models currently used for a hydrogen release from pipelines.

2.0 GENERAL DESCRIPTION OF THE DRAFT DOCUMENT

The draft document covers the safety rules intended to regulate the systems for the compressed gaseous hydrogen transport and delivery by means of pipelines, from the production facilities to the consumer sites; these safety rules also apply to the installations within the industrial areas. A pipeline is defined herein as an assembly of pipes, valves, curves, fittings and other special components which are putted together in order to transport and delivery compressed gaseous hydrogen.

The text of the draft document follows the model of the fire prevention regulations for natural gas pipelines (D.M. 24/11/84 - Part 1 [4]); it has been properly adapted to the specificities connected with the hydrogen use. This way has been considered the quickest to be covered in order to achieve a good technical document concerning the hydrogen pipelines, similarly to the previous work on the hydrogen refuelling stations [1]. As it will be seen, most instructions are suitable because a compressed gas is delivered by means of pipelines.

The text contents are divided into the following Sections:

- Section 1: General instructions
- Section 2: Pipelines for a maximum operating pressure greater than 0.5 MPa
- Section 3: Pipelines for a maximum operating pressure up to and including 0.5 MPa
- Section 4: Compression facilities
- Section 5: Pressure reduction facilities
- Section 6: Installations within the industrial areas

The instructions have been given consistently with those contained in the D.M. 31/08/2006 [2] about the fire prevention for the gaseous hydrogen refuelling stations because similar systems are present in these installations (e.g. the compression facility and the pressure reduction facility). On the analogy of the hydrogen refuelling stations, the hydrogen production facilities shall be the subject of a specific risk analysis [1, 2, 5].

The instructions are provided according to the maximum operating pressure of the system which is defined as the maximum gauge pressure [MPa] for the system operation. For this purpose a pipeline is classified with reference to the following Classes (as a measure of conservation, they are identical to those provided in D.M. 24/11/84):

a) Class 1: pipelines for a maximum operating pressure greater than 2.4 MPa up to and including 3.0 MPa

b) Class 2: pipelines for a maximum operating pressure greater than 1.2 MPa up to and including 2.4 MPa

c) Class 3: pipelines for a maximum operating pressure greater than 0.5 MPa up to and including 1.2 MPa

d) Class 4: pipelines for a maximum operating pressure greater than 0.15 MPa up to and including 0.5 MPa

e) Class 5: pipelines for a maximum operating pressure greater than 0.05 MPa up to and including 0.15 MPa

f) Class 6: pipelines for a maximum operating pressure greater than 0.004 MPa up to and including 0.05 MPa

g) Class 7: pipelines for a maximum operating pressure up to and including 0.004 MPa

The Class 1 pipelines are usually intended to transport hydrogen gas from the production facilities until to the sites where it will be used and to connect the users located outside the built-up areas. The Class 2 pipelines are usually intended to connect Class 1 pipelines to Class 3 pipelines and to connect the users located on the outskirts of the built-up areas. The Class 3 pipelines are usually intended to form local delivery networks. The Class 4, 5, 6 and 7 pipelines are usually intended to form the pipe networks for the hydrogen delivery to the user's equipment.

Pipes, valves, curves, fittings and other special components used in the hydrogen pipelines shall be designed, constructed and tested in accordance with the requirements of the Pressure Equipment Directive (PED) 97/23/EC [6]; anyhow, these components shall be manufactured and tested on the basis of suitable specified standards. Furthermore, the hydrogen pipelines shall be marked for identification according to the regulations in force; information about the contained gas, its direction of flow and its maximum operating pressure shall be reported.

Among the 97 facilities and activities under National Fire Corps control [7], the hydrogen transport in pipelines falls within the activity n. 6, titled "Pipe networks intended to transport and delivery fuel gases (including those of oil or chemical origin), except the civic delivery networks and the relevant systems with an operating pressure not greater than 0.5 MPa". Therefore the civic delivery networks and the relevant systems with an operating pressure not greater than 0.5 MPa are not subjected to the fire prevention procedure (preventive assessment of plans and installations, and subsequent control inspection) [1]; however, they shall comply with the instructions of the future law on the hydrogen pipelines because they are included within its field of application. This is a general remark about the fuel gas transport in pipelines, apart from the specific gas in use.

2.1 Fire safety for the hydrogen pipelines (Section 2 and Section 3)

Pipelines fire safety is pursued through the following means:

a) Use of suitable materials.

Hydrogen service generally reduces the mechanical properties of certain materials by the complex process of embrittlement. Therefore each involved material should be carefully evaluated for its use in hydrogen pipelines.

Pipes, valves, curves, fittings and other special parts used for the manufacturing of hydrogen pipelines shall be of metallic material. These materials shall be in accordance with the requirements of the Pressure Equipment Directive (PED) 97/23/EC [6] and with the instructions of ISO/TR 15916, *Basic*

considerations for the safety of hydrogen systems [8] and IGC Doc 121/04/E, *Hydrogen Transportation Pipelines* [9]. Material accordance shall be attested by the supplier on its own responsibility.

b) Connections of the components

The connections of valves, curves, fittings and other special parts can be realized by a flange coupling, a butt welding or a thread coupling (the latter only for pipelines belonging to the Classes 4, 5, 6 and 7). The valves shall to be undergone to a hydraulic strength test of their body and to a hydrostatic test. The isolation valves shall be in preference ball valves.

c) Pipes thickness

The draft document provides formulas depending on the design pressure, the pipe diameter and the material properties. However, a minimum thickness has to be assured; it is specified by the technical rule itself.

d) Dissections

The pipelines should be dissected by intercepting devices. The intercepting devices should be located in order to be easily attainable. The section lengths depend on the pipeline Class; they are identical to those prescribed for the natural gas pipelines [4]. Each section shall be provided with suitable discharging devices; they are intended to empty the section quickly by manual activation; the points of discharge shall be located in open areas.

e) Operating pressure control

Besides the main pressure reducer, a suitable safety device (e.g. second pressure reducer in series or locking device, etc.) and an automatic device for the discharging into atmosphere shall avoid the exceeding of the maximum operating pressure. They shall be installed at the head of the pipeline section; their setting values depend on the pipeline Class.

f) Operating flow rate control

Suitable excess flow devices shall avoid the exceeding of the maximum operating flow rate. They shall be installed at the head of each pipeline section.

g) Pipe-laying - Depth of the burial

The pipelines shall be buried as a rule; the depth of the burial depends on the pipeline Class. In special cases specified by the text, a pipeline can be buried at lower depth or even located aboveground. The location aboveground is allowed in the event of clear technical difficulties (e.g. crossing of watercourses or unstable soils, switching junctions).

h) Pipe-laying - Parallelisms and crossings

Instructions are provided in the event of a pipeline parallelism or crossing with railway lines, urban or suburban tramlines, national and provincial roads, motorways, watercourses and pre-existent canalizations (e.g. for electric and telephone cables, sewerage systems, etc.). These instructions are too specific and cannot be detailed here. They mainly consist of safety distances and use of protection tubes.

i) Pipe-laying - Safety distances from buildings and maximum operating pressure

As regards the pipe-laying of the Classes 1, 2 and 3, the maximum operating pressures and the minimum safety distances from buildings are set by means of a suitable table depending on the pipe diameter, the features of the soil, the type of protection system and the pipe-laying conditions. As

regards the pipe-laying of the Classes 4 and 5, the minimum safety distances from buildings are set depending on the only pipe-laying conditions. As regards the pipe-laying of the Classes 6 and 7, minimum safety distances are not provided. The considered pipe-laying conditions are the following:

- Category A: pipeline sections laid in soil provided with an impermeable surface layer

- Category B: pipeline sections laid in soil unprovided with an impermeable surface layer

- Category C: as Category A but where gas draining is allowed by carrying out a very permeable zone around the pipeline section (greater than the permeability of the surrounding soil) and by providing spaced vent devices

- Category D: pipeline sections laid in pipes or special systems and provided with suitably spaced diaphragms and vent devices

The entities of the safety distances will be evaluated following the experimental testing performed with the H.P.B.T. apparatus described below.

l) Pipe-laying - Pipelines junctions

The pipe junction performed to assemble a pipeline at the installation location shall be carried out by a fusion welding. A specified percentage of the joints shall be inspected with nondestructive techniques and the relevant test report shall be produced. Use of flange, thread and different special coupling shall be reduced to a minimum; the suitable documentation shall be presented.

m) Pipeline testing

After the pipe-laying, the pipeline sections shall be pressure tested. The pressure test should be performed hydraulically but the use of air or inert gases can be allowed; the test values depend on the pipeline Class. The requirements for a favourable test are specified.

n) Protection against corrosion

The buried pipelines shall be provided with a protective coating against the aggressive actions from the environment where they are located and against corrosion from natural and stray electrical currents. The suitability of the used materials is attested by the installation firm, under its own responsibility.

In order to increase the protective action coming from the coating, the cathode protection shall be applied during the operation. It cannot be applied to pipeline stretches of limited length, provided with efficient coating and electrically separated from remainder of pipeline by means of insulating joints.

The pipelines stretches installed at the open air shall provided with protective coatings or paintings against the atmospheric corrosion from the environment where they are located. The suitability of the protective methods or systems is attested by the installation firm, under its own responsibility.

2.2 Compression and pressure reduction facilities (Section 4 and Section 5)

The instructions are provided according to the outlet pressure (compression facilities) or the inlet pressure (pressure reduction facilities). The compression facilities were not taken into consideration in the regulations for the natural gas pipelines. However, only the compression facilities with an outlet pressure greater than 1.2 MPa are regulated by the draft document because only these types of facilities will be probably installed (e.g. downstream production facilities or along the lines in order to raise the gas pressure sufficiently).

The instructions address the following:

a) Location and construction of the possible premises containing the compression or pressure reduction systems

The compression or pressure reduction facilities shall be located indoors. Similarly to the hydrogen refuelling stations [1] the premises shall be provided with 1st or 2nd level safety features according whether the premises characteristics guarantee, in the event of a possible burst, either materials containment both in side direction and in upward direction (1st safety level) or only in side direction (2nd safety level). Furthermore, these facilities shall be enclosed and the enclosure shall be realized at a distance equal to the protection distance [1] set for the specific facility, according to the maximum operating pressure in the gas system. However, it should be noted that the pressure reduction facilities with an inlet pressure up to 1.2 MPa are an exception in view of the low pressure values; therefore they can be installed without enclosure and can be provided only with 2nd level safety features.

b) Safety of the main gas system

The safety measures for the main gas system are essentially those provided for the pipelines:

- junction of the circuit components performed by a fusion welding; flange couplings, thread couplings and other special couplings shall be reduced to a minimum but also provided with the documentation attesting their suitability

- use of suitable materials and suitable tubes thickness

- pressure testing of the gas system in order to check the suitability of the junctions; it is performed by a hydraulic test with different setting values depending on the pipeline Class in the different sections of the gas system

- protection against corrosion with methods similar to those previously specified

- gas flow interception by means of devices easily attainable; they shall be located inside the enclosure but outside the premises, if existing

- operating pressure control by means of devices similar to those previously specified (safety devices and discharging devices)

- operating flow rate control by means of excess flow devices similar to those previously specified; they shall be located at the head of main gas system and installed inside the premises, if existing

The differences relevant to the specific operating pressure in the gas system are not here reported.

2.3 Installations within the industrial areas (Section 6)

The installations within the industrial areas usually consist of the following systems:

- a hydrogen production facility and the possible compression facility

- a pipeline delivering hydrogen from the production facility or the outer pipe network to the pressure reduction and measurement facility of the consumer (feeding line)

- a pressure reduction and measurement facility

- a pipe network delivering hydrogen from the pressure reduction and measurement facility to the equipment (adduction network)

All the above-mentioned systems shall be designed, constructed and tested according to the instructions of the previous Sections. Furthermore, the following documents shall be available at these installations:

- the operating manual containing the instructions intended to operate and make safe the facilities

- the simplified flow diagram of the installations

- the plan of the delivering lines with the mark of the critical facilities in the neighbourhood

If the maximum operating pressure is greater than 0.5 MPa, the installations within the industrial areas shall be the subject of a specific risk analysis [8]. In this case the risk analysis is considered an essential tool: specific instructions cannot be provided in view of the different and not foreseeable system layouts within an industrial area. Therefore, the location of the facilities, the route of the feeding line and the route of the adduction network shall be evaluated consistently with the results from the risk analysis. If those results cannot be met, an emergency system shall be provided in order to allow the isolation of the line and its scavenging by means of nitrogen. The activation of this safety system shall be possible not only by the installed detection systems but also by an easily attainable, manually-activated device located in a sheltered place.

3.0 EXPERIMENTAL STUDIES ON THE HYDROGEN RELEASES FROM PIPELINES

The experimental apparatus named H.P.B.T. (Hydrogen Pipe Break Test) has been installed within the Laboratory "Scalbatraio" belonging to the University of Pisa. This apparatus is intended to investigate the behaviour of the hydrogen leakages from the pipelines; it can simulate a real, low pressure hydrogen release into free air, the ignition of hydrogen-air mixtures and the possible evolution of the consequent combustion. The experimental activity will provide technical information about the gas diffusivity depending on the release position, about the ignition parameters and the characteristics of the possible shock wave caused by ignition. Only large size leaks are taken into account at the moment because the main aim is the investigation of the break evolution and the accident course. Further studies on smaller leakages can be accomplished easily, if the release orifice dimension is reduced.

3.1 Apparatus layout

The H.P.B.T. apparatus can be subdivided into four ideal parts (Fig. 1 and Fig. 2):

1. High pressure gas storage. There are two sets of high pressure gas storage: the first one contains the hydrogen used for the testing; the second one contains the nitrogen to remove the air into the apparatus at the start of the testing series and to remove the residual hydrogen at their conclusion. Each set consists of twenty five cylinders with an initial pressure equal to 20 MPa.

2. Gas tanks (test pressure). They are four large storage tanks (3 m^3 each) with a maximum hydrogen pressure of 1 MPa; therefore it is possible to store up to 130 Nm^3 of hydrogen. They are connected to the high pressure storage by a pipe of 2 in (0.0508 m) in diameter; the feeding valve will be closed during the gas release. The gas tanks deliver hydrogen to the pipeline system by a discharge manifold. They are also connected to the vent line directly.

3. Pipeline system. A pipe of 4 inches (0.102 m) in diameter and 50 m long starts from the gas tanks and moves away towards a large free area. It is provided with an automatic release system (A.R.S.) at the far end. When the A.R.S. is turned on, it opens in tenths of second and can be closed when desired. The A.R.S. consists of two different valves series connected: the first valve is a pneumatic ball valve and opens in few seconds, the second valve is a pneumatic fast opening valve simulating the leakage. A sparkle will allow the ignition. The line length allows the simulation of a real pipeline and also guarantees a safety distance between the gas storage and the release point.

4. Vent line. A further pipe of 2 inches (0.0508 m) finishes in a 6 m high vent that is able to dispel the gas, if it is necessary. It is a safety system used in the event of an apparatus malfunctioning or a gas tanks overpressure. It will also be used to remove residual hydrogen from the tanks by compressed nitrogen in order to leave inert gas inside the plant between two sets of tests.

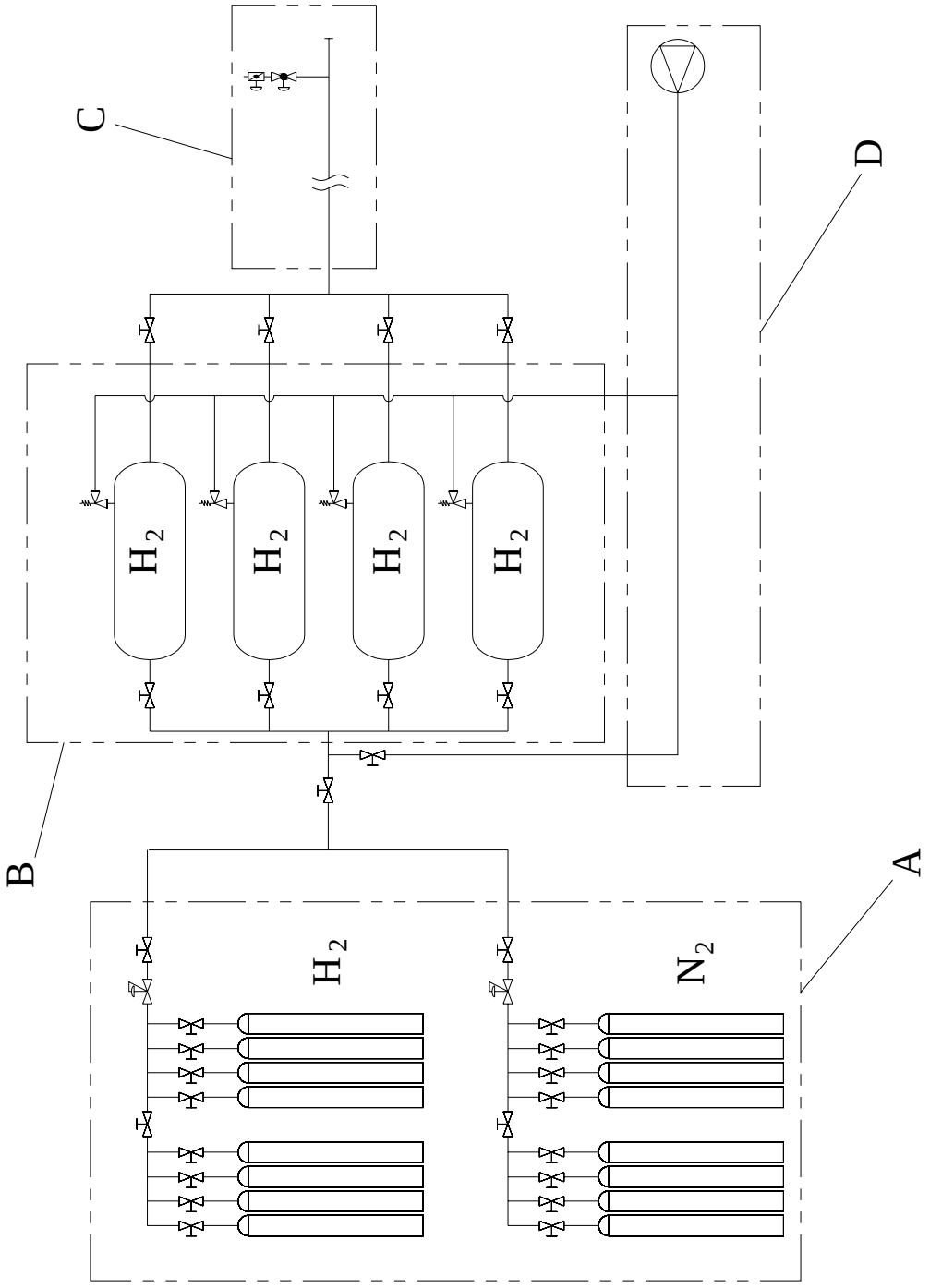

Figure 1. H.P.B.T. layout: (A) high pressure gas storage, (B) gas tanks (test pressure), (C) pipeline system and (D) vent line.

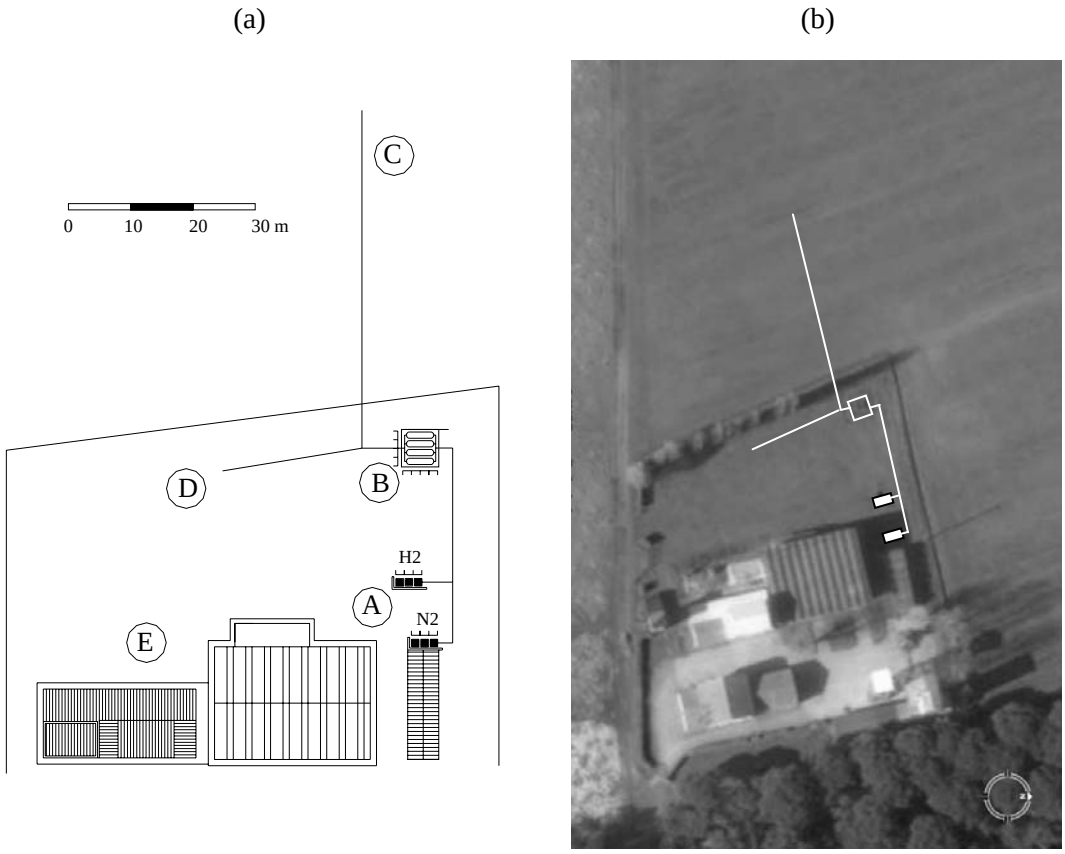

Figure 2. H.P.B.T. layout, (a) aerial view: (A) high pressure gas storage, (B) gas tanks (test pressure), (C) pipeline system, (D) vent line and (E) the existing building; (b) satellite picture.

3.2 Experimental tests

In order to carry out a test, the air is first removed from the apparatus by nitrogen scavenging. Then the gas tanks will be filled with hydrogen and the apparatus will be set up to start the test. The automatic release system is turned on, the gas flows out of the test orifice until the pressure into the tanks drops to a value previously chosen for the test and then the automatic system stops the leakage.

Two different kinds of test can be accomplished:

1. the hydrogen is simply released
2. afterwards, the release is ignited by a sparkle.

Several different parameters can be changed during the tests:

- orifice size; currently three orifices have been chosen: Ø 5 - 11 - 22 mm
- angle of release; each angle has a discrete variation of 45° beginning from the vertical direction
- internal pressure; up to a maximum of 1 MPa
- release time; it depends on the orifice size and the internal pressure (30 s < t < 240 s)

The gas pressure is the easiest parameter to be modified while the orifice size and the angle of release are more complicated.

Table 1 reports a schedule of the tests which will be carried out in order to achieve enough data to take

the decision on the parameter values in the subsequent tests.

Table 1. H.P.B.T. test parameters.

Orifice diameter [mm]	Internal pressure [MPa]	Angle of release 	Release time [s]	Amount of gas release per test [Nm^3]	Maximum gas flow rate through the orifice [g/s]
5	0.3	0 - 45 - 90 - 135 - 180	240	6	2.2
	0.5	0 - 45 - 90 - 135 - 180	240	11	3.8
	1	0 - 45 - 90 - 135 - 180	240	20	7
11	0.3	0 - 45 - 90 - 135 - 180	90	10.5	11
	0.5	0 - 45 - 90 - 135 - 180	90	17.5	18
	1	0 - 45 - 90 - 135 - 180	90	35	36
22	0.3	0 - 45 - 90 - 135 - 180	30	13.5	44
	0.5	0 - 45 - 90 - 135 - 180	30	22	73
	1	0 - 45 - 90 - 135 - 180	30	44	140

The following experimental data can be acquired:

a) with reference to the gas system, it will be possible to take measurements of:

- temperature inside the apparatus
- pressure inside the gas tanks and pressure variations during the gas release
- mass flow rate of the gas into the pipe during the gas release

b) with reference to the gas release, it will be possible to take measurements of:

- gradient of the hydrogen concentration in air
- pressure peaks
- atmospheric conditions (temperature, wind speed, wind direction and humidity)
- flame temperature, in case of ignition

Furthermore thermocameras and videocameras will be used to film the phenomena in the various conditions.

In order to get data about the hydrogen concentration outside the pipeline and to make visible the gas jet and the jet fire, a large volume around the release orifice will be covered with very thin mist. During the gas release the flux will be visible as it drags along the mist. If the sparkle ignites the gas-air mixture and if the mist contains some salt, the jet fire will result coloured by the burning salt.

Finally, it is important to underline that changes in atmospheric conditions will affect all the dynamics of the testing: hence the necessity of an accurate measurement of the humidity, the wind speed and its direction.

4.0 CONCLUSIONS

The prospective development and diffusion of the systems for the hydrogen production, storage and delivery have to deal with the specific safety issues relevant to design, construction and operation of the lines for the gas transfer. The Italian Working Group on the fire prevention safety issues has drawn up a proper draft of technical rule beginning from the standard model covering the natural gas pipelines. This paper has discussed the main characteristics and instructions herein.

The selection of suitable materials and the hydrogen releases are the new, main safety issues from the fire prevention point of view. For the first issue, the standards and regulations in force provide a number of useful requirements and information in order to deal with the proper selection. For the second issue, a specific apparatus, named H.P.B.T. (Hydrogen Pipe Break Test) has been designed and installed at the laboratories of the University of Pisa. The experimental data will be useful not only for the completion of the technical rule but also for the comparison with theoretical and computational release models.

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