English translation

AR 214
January 2024

Approval requirement 214

Suitability of gas distribution and installation materials for admixtures with Hydrogen and full hydrogen gas

kiwa

GASTEC

Certification Hydrogen Gas

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Foreword Kiwa

This GASTEC QA approval requirement (translation of the Dutch version) has been approved by the Board of Experts product certification GASTEC QA, in which relevant parties in the field of gas related products are represented. This Board of Experts supervises the certification activities and where necessary require the GASTEC QA approval requirement to be revised. All references to Board of Experts in this GASTEC QA approval requirement pertain to the above mentioned Board of Experts.

This GASTEC QA approval requirement (translation of the Dutch version) will be used by Kiwa Nederland BV in conjunction with the GASTEC QA general requirements and the KIWA regulations for certification.

This approval requirement is a translation from the Dutch validated version and can only be used as supporting document.

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1 Introduction

1.1 General

This GASTEC QA – Hydrogen gas approval requirement in combination with the GASTEC QA general requirements include all relevant requirements, which are adhered by Kiwa as the basis for the issue and maintenance of a GASTEC QA – Hydrogen gas certification certificate fitness for admixtures up to and including 100% hydrogen gas.

This GASTEC QA approval requirement replaces the GASTEC QA approval requirement 214 “Fitness for admixtures up to and including 100% hydrogen gas”, dated September 2022.

List of changes:

- The approval requirement is fully reviewed and updated textually
- Added are the paragraph which relates to:
    - Leak tightness criterion (which caused the deletion of the appendix as metioned in the previous version of the AR)
    - Permeation of Hydrogen
- The testmedium for all tests is hydrogen
- Definitions updated
- Bibliography updated

A certificate based on this approval requirement will only been issued in combination with a valid and active GASTEC QA product certificate for natural gas.

1.2 Field of application / scope

This approval requirement is applicable to gas distribution and installation materials for natural gas with an admixture of 20% hydrogen gas and full hydrogen gas with 98%vol as lowest limit.

The maximum operating pressure (MOP) and operating temperature are specified in the approval requirement for the product for GASTEC QA certification.

Remarks:
Considering the hydrogen application area, the following aspects have been taken into account:

- Hydrogen embrittlement – no impact regarding the scope of this AR:
  From all studies published to date, it can be concluded that hydrogen embrittlement does not occur for the metals (steel, stainless steel and cast iron) that can be used or will be used in the gas distribution network.[1][2]
  A test/requirement aimed at resistance to hydrogen embrittlement is therefore not included in this inspection requirement.
- Permeation – no impact regarding the scope of this AR:
  Research has shown that the permeation loss that occurs with hydrogen is more than when using natural gas, but is well below the accepted limit for leaks.[3]

2 Definitions

In this approval requirement the following terms and definitions apply:

Add-on: in addition to

Board of Experts: Board of Experts GASTEC QA.

Decree quality of gas: Regulation from the Minister of Economics for determine the requirements for gas quality.

Distribution materials: Materials applied before the meter and whose scope is defined in the NEN 7244 series.

Hydrogen gas: with Hydrogen and Hydrogen gas is meant: Di-hydrogen or molecular hydrogen (H_2), the main singular material from the element hydrogen. At normal pressure and temperature hydrogen gas is colourless, odourless, tasteless and highly flammable.

Hydrogen embrittlement: a fracture mechanism that occurs as a result of degradation of the mechanical properties.

Installation materials: Materials applied after the meter and whose scope is defined in NEN 1078 or NEN 8078 (see design and application).

Laminar flow: A flow in which the layers of a gas or liquid move parallel to each other. There is little or no flow perpendicular to the main flow**.**

Sealing materials: Materials used for sealing threads according to approval requirement 31-1, 31-2 and 31-3.

Suitability for hydrogen: Products that satisfy the requirements included in this approval requirement are deemed to be suitable to be used with an admixture for hydrogen gas and pure hydrogen gas.

MOP: Maximum Operating Pressure.

Permeation: Permeation is a natural process in which the permeate (a liquid, gas or moisture) moves through a solid.

Resistance to hydrogen: The extent materials used for the manufacture are resistant to long-term exposure to admixtures of hydrogen gas and natural gas and pure hydrogen gas.

Turbulent flow: A flow that does not move in layers, but in vortices. There is a lot of flow perpendicular to the main flow.

Other definitions are available in the relevant GASTEC QA approval requirements.

3 Product requirements

3.1 General

Products approved by this approval requirement shall fulfil the requirements GASTEC QA approval requirements belonging to the product first for which a product certificate will be issued. The related approval requirement is mentioned on the certificate of the product.
A modification to the product so that it is suitable for hydrogen application results in a initial certification after which the AR 214 can be followed.

3.2 Materials

AR 214 is an 'Add-on' and can only be followed when a GASTEC QA product certificate has been issued, see 3.1. As a result, the material requirements for the related product have already been covered with respect to the conditions (such as pressures and temperatures) described in the scope of the associated approval requirement.

During the initial certification according to AR 214, the components that come into (in)direct contact with hydrogen will be verified.
For materials whose resistance to hydrogen gas is unknown, or where there is doubt about their suitability for the field of application, the suitability must be demonstrated so that the materials can be used safely in combination with hydrogen gas:
If the evidence is insufficient, the product will be exposed to a long-term test in which the product (so also the material self) is in direct contact with 100% hydrogen, after which the product is tested on the internal and/or external leak-tightness.

4 Performance requirements and test methods

4.1 General

Several products require additional testing. These products are listed in table 1, indicating which tests shall be performed. Other products do not require additional testing.

Products:	Leak tightness internal	Leak tightness external	Long-term behaviour	Functionality
Valves (AR 69(-1))	X	X	X	
Gas pressure regulators, gas leak protectors and combination regulators (AR 11)	X	X	X	X
Maximum flow rate safety valves* (AR 191)	X	X	X	X
Gas stopper** (AR 210)	X		X	X
Equipment for temporarily closing off gas pipes (AR 194)	X	X	X	
Thermally responsive safety valve (AR 171)	X	X		X

Table 1: Performance requirements

*Excess flow valves are applied in houses and buildings and can be installed in pipes.
**Gas stoppers are used in distribution pipe systems outdoor in or near a saddle.

4.1.1 Test pieces, medium, criterion factor 0,73 and 3

When testing the performance requirements, test pieces are tested in accordance with the corresponding GASTEC QA approval requirement.

All tests mentioned in table 1 are carried out with the medium hydrogen.

For the hydrogen application area, the following maximum permitted leakage limits (criterion)[4] are used:

- for products in the current natural gas and future hydrogen gas network up to and including 200 mbar: 74% of the current requirement, as mentioned in the paragraphs of Chapter 4.
- For products in the current natural gas and future hydrogen gas network, for pressures above 200 mbar: 3 times the requirement for natural gas, as mentioned in the paragraphs of Chapter 4.
- A three times larger volume flow of hydrogen compared to natural gas has been taken into account.

The substantiation of the above is included in Appendix A.

4.1.2 Determination of leak tightness

The leak tightness is determined with the medium hydrogen. The uncertainty of the equipment gas shall not exceed 5 cm^3/h.

For products not listed in table 1, first the material will be verified (see 3.2) after which the test results of the initial certification of the product, in accordance with the applicable approval requirement, will be used to prove meeting the requirements.

4.1.3 Long-term behavior

The long term behavior shall be tested with hydrogen gas. If applicable, a leak tightness test before or after the functional test, is performed also with the medium hydrogen according to paragraph 4.1.2.

4.1.4 Functionality

The functionality of the product shall be tested with 2 concentrations of test gases. First with 20% hydrogen gas in natural gas and next with pure hydrogen gas. If applicable, a leak tightness test before or after the functional test, is performed with the medium hydrogen according to paragraph 4.1.2.

4.2 Leak tightness internal

Take into account that in the paragraphs below (part of 4.2), the permitted leakage rates mentioned will be corrected with the criteria from 4.1.1.

4.2.1 Valves

The valves shall be tested in closed position with the testing equipment connected to 1 side.

Valves	Requirement	Test medium	Test time	Test temperature	Test pressure
AR 69 (-1)	≤50 DN: 6.6 cm3/h 50<DN≤100: 13.3 cm^3/h	hydrogen	10 minutes low pressure followed by 10 minutes high pressure	23 ± 2 °C	6 mbar followed by 1.5 x MOP

Table 2: Test parameters for internal leak tightness of valves

4.2.2 Regulators

The gas pressure regulator and combination regulator shall be tested with the control valve in closed position. The inlet and outlet sides are connected to a leak tight measuring system with pressures that can be set independently from each other.

The internal leak tightness of a gas pressure regulator and a combination regulator shall be measured at a pressure of 300 mbar at the inlet side and 37.5 mbar at the outlet side. The internal tightness test is performed according to approval requirement 11.

In order to determine the amount of leakage of hydrogen, whereby the pressure regulator can be regarded as internally leak tight, the permitted maximum amount of leakage in accordance with approval requirement 11 shall be converted using 4.1.1.

4.2.3 Maximum flow rate safety valves

When the valve is completely closed, leakage shall not exceed 1.0 dm^3/h. This leakage shall be determined according to approval requirement 191, paragraph 4.4.

4.2.4 Gas stoppers

At a test pressure of 1x MOP, the leakage flow with a fully closed gas stoppers shall not exceed 1 dm^3/h for gas stoppers without bypass and one third of the manufacturer's stated value (for natural gas) for gas stoppers with bypass. The leakage flow will be tested according to approval requirement 210, paragraph 5.6.

4.2.5 Thermally responsive safety valve

Leakage when the valve is completely closed shall not exceed 10 dm^3/h. This leakage will be determined according to approval requirement 171, paragraph 4.6.

4.2.6 Equipment for temporarily closing off gas pipes

The leakage of the closing element for pipes within a building shall not exceed 1.65 dm^3/h. This leakage shall be determined according to approval requirement 194, paragraph 4.2.4.

The leakage of the closing element for pipes outside a building shall not exceed 0.1 dm^3/h. This leakage shall be determined according to approval requirement 194, paragraph 4.2.5.

The leakage of the closing element in a drill hole shall not exceed 0.1 dm^3/h. This leakage shall be determined according to approval requirement 194:2019, paragraph 4.2.6.

4.3 Leak tightness external

External leak tightness shall be carried out on the products listed in table 2 and determined in accordance with paragraph 4.1.2 as well as the test method of the corresponding product approval requirement. The permitted leakage rates will be corrected with the criterion mentioned in 4.1.1.

4.4 Long-term behavior

Take into account that in the paragraphs below (part of 4.4), the permitted leakage rates mentioned will be corrected with the criteria from 4.1.1.

4.4.1 General

Testing of long-term behavior is performed according to paragraph 4.1.3 and the following methods.

4.4.2 Valves

For this test, the cut-off valves that were tested as per 4.2.1 will be used. The valves, after the number of times of opening and closing according to the GASTEC QA approval requirement associated to the valve, shall be leak tight according to paragraph 4.2.1 and 4.3.

4.4.3 Gas pressure regulator and combination regulator

The gas pressure regulator and the combination regulator, after 40.000 times of opening and closing of the control valve at an environmental temperature of -20 ± 1 °C and subsequently after 40,000 times of opening and closing at an environmental temperature of 50 ± 1 °C shall satisfy the requirements of paragraph 4.2.2 and 4.3.

4.4.4 Gas leak protectors

A gas leak protector (GGB) and a combination regulator with closed inlet side, however with the outlet side connected to a varying pressure of 0 mbar to 25 mbar, after 5,000 times of opening and closing of the closing element at an environmental temperature of -20 ± 1 °C and subsequently after 5,000 times of opening and closing at an environmental temperature of 50 ± 1 °C shall satisfy the requirements of paragraph 4.3.

4.4.5 Maximum flow rate safety valves

After repeatedly (10 times) closing and opening the valve, according to approval requirement 191, paragraph 4.5, it shall still satisfy the requirements according to paragraph 4.2.3 and 4.3.

4.4.6 Gas stoppers

After repeatedly (100 times) closing and opening the gas stoppers with a test piece at 1x MOP, it shall still satisfy the requirements according to paragraph 4.2.4.

4.4.7 Equipment for temporarily closing off gas pipes

After repeatedly installing the insertion element through the valve seat, the seal between the insertion element and the attachment shall be leak tight according to paragraph 4.3.

4.5 Functionality

Take into account that in the paragraphs below (part of 4.2), the permitted leakage rates mentioned will be corrected with the criteria from 4.1.1.

4.5.1 Gas pressure regulator and combination regulator

The gas pressure regulator and the combination regulator shall satisfy the requirements of approval requirement 11, pressure regulation, silence, and vibration. The test shall be performed with the 2 concentrations of test gases according to paragraph 4.1.4.

When there is 20% hydrogen gas in the natural gas, the flow rate specified for natural gas shall be applied. When using pure hydrogen gas, the flow rate times 3 for natural gas shall be applied.

4.5.2 Gas leak protector

A gas leak protector (GGB) device shall satisfy the requirements of approval requirement 11, pressure regulation, silence, and vibration. The test shall be performed with the 2 concentrations of test gases according to paragraph 4.1.4.

When there is 20% hydrogen gas in the natural gas, the flow rate specified for natural gas shall be applied. When using pure hydrogen gas, the flow rate times 3 for natural gas shall be applied.

4.5.3 Maximum flow rate safety valves

The flow rate at which the safety valve closes shall be at least 10% and at the most 30% more than the nominal flow rate as specified by the manufacturer. The test shall be performed with the 2 concentrations of test gasses according to paragraph 4.1.4 and the method according to approval requirement 191, paragraph 4.3.

When there is 20% hydrogen gas in the natural gas, the flow rate specified for natural gas shall be applied. When using pure hydrogen gas, the flow rate times 3 for natural gas shall be applied.

4.5.4 Gas stoppers

The gas stoppers applied in a piping system with an MOP of 200 mbar shall not close at a sudden increase of the flow rate from nominal to 115%. The test shall be performed with the 2 concentrations of test gasses according to paragraph 4.1.4, and the method according to approval requirement 210, paragraph 5.6.

When there is 20% hydrogen gas in the natural gas, the flow rate specified for natural gas shall be applied. When using pure hydrogen gas, the flow rate times 3 for natural gas shall be applied.

4.5.5 Thermally responsive safety valve

40 seconds after insertion of the test piece in the oven, the valve shall close completely. The test shall be performed with the 2 concentrations of test gasses according to paragraph 4.1.4 and the method according to approval requirement 171, paragraph 4.6.

When there is 20% hydrogen gas in the natural gas, the flow rate specified for natural gas shall be applied. When using pure hydrogen gas, the flow rate times 3 for natural gas shall be applied.

5 Marking and instructions

5.1 Marking

The marking shall be according to the requirements of the GASTEC QA approval requirement of the product.
In addition, the product and/or packaging shall be marked with:

- The words “Bestand tegen waterstofgas volgens KE 214” or “Hydrogen ready according to AR 214”.
- For pressure regulators, gas stoppers and thermal responsive safety valves: the flow rate at 20% and full (with 98% as lowest limit) hydrogen.

In case the marking does not fit on the product, this need to be applied on the smallest packaging.

5.2 Instructions

The instruction document shall be according to the requirements of the GASTEC QA approval requirements of the product. In addition, the instruction document shall mention the product is suitable to use in gas distribution systems or indoor installations for hydrogen gas.

Remark: for adjusting the marking and instruction documents of existing products, it’s allowed to fulfil the requirements by using a sticker on the product and documents during the time needed for adjusting the marking and documentation.

6 Summary of tests

This chapter contains a summary of tests carried out during:

- The initial product assessment;
- The periodic product verification;

6.1 Text matrix

Description of requirement	Clause	Test within the scope of		
		Initial product assessment	Product verification	
			Verification	Frequency
Product requirements	3			
General	3.1	X		
Material	3.2	X	X	Once a year
Performance requirements	4			
General	4.1			
Leak tightness internal	4.2			
Valves	4.2.1	X	X	Once a year
Gas pressure regulators, gas leak protectors and combination regulators	4.2.2	X	X	Once a year
Maximum flow rate safety valves	4.2.3	X	X	Once a year
Gas stopper	4.2.4	X	X	Once a year
Thermally responsive safety valve	4.2.5	X	X	Once a year
Equipment for temporarily closing of gas pipes	4.2.6	X	X	Once a year
External leak tightness	4.3	X	X	Once a year
Long-term behavior	4.4			
General	4.4.1			
Valves	4.4.2	X	X	Once a year
Gas pressure regulator and combination regulator	4.4.3	X	X	Once a year
Gas leak protector (GGB)	4.4.4	X	X	Once a year
Maximum flow rate safety valves	4.4.5	X	X	Once a year
Long-term behavior gas stoppers	4.4.6	X	X	Once a year
Equipment for temporarily closing off gas pipes	4.4.7	X	X	Once a year
Functionality	4.5			
Gas pressure regulator and combination regulator	4.5.1	X	X	Once a year
Gas leak protector (GGB)	4.5.2	X	X	Once a year
Maximum flow rate safety valves	4.5.3	X	X	Once a year
Gas stoppers	4.5.4	X	X	Once a year
Thermally responsive safety valve	4.5.5	X	X	Once a year
Marking and instructions	5			
Marking	5.1	X	X	Once a year
Instructions	5.2	X	X	Once a year

7 Titles of standards and sources

7.1 List of underlying approval requirements

All references in this GASTEC QA approval requirement remit to the version of the relative document in accordance with the following list.

Approval requirement 1	Approval requirement 5
Approval requirement 6	Approval requirement 7
Approval requirement 8	Approval requirement 10
Approval requirement 11	Approval requirement 15
Approval requirement 31-1	Approval requirement 31-2
Approval requirement 31-3	Approval requirement 34
Approval requirement 35	Approval requirement 43
Approval requirement 50	Approval requirement 52
Approval requirement 58	Approval requirement 69
Approval requirement 69-1	Approval requirement 70
Approval requirement 81	Approval requirement 87
Approval requirement 91	Approval requirement 120
Approval requirement 136	Approval requirement 137
Approval requirement 154	Approval requirement 156
Approval requirement 165	Approval requirement 168
Approval requirement 171	Approval requirement 172
Approval requirement 186	Approval requirement 191
Approval requirement 192	Approval requirement 194
Approval requirement 197	Approval requirement 198
Approval requirement 200	Approval requirement 201
Approval requirement 206	Approval requirement 207
Approval requirement 208	Approval requirement 209
Approval requirement 210	Approval requirement 211
Approval requirement 212	Approval requirement 213

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In case an approval requirement is not listed in the previous list, e.g., become active after this version is established, a judgement will take place if it can be accepted for the use with hydrogen.

7.2 Sources

[1] Kiwa report GT-170272 “Toekomstbestendige gastdistributienetten”
[2] Kiwa report GT-200134 “Invloed van Waterstof op Staal”
[3] Kiwa report GT-220044 “Permeatie van waterstof”
[4] HyDelta report: WP 1C Pipes and indoor installations, D1C.2 question number 124 – Tighness of distribution pipes’;

Parts of the text of this approval requirements are based on:

- NEN 7239:2018 – ‘Gas pressure regulators, gas leak protectors and gas pressure regulators combined with gas leak protectors for domestic installations with a capacity up to 10 m3 and an inlet pressure (MOP_u) up to 200 mbar’
- EN 331:2015 – ‘Manually operated ball valves and closed bottom taper plug valves for gas installations for buildings’
- Kiwa report GT-200237 “De invloed van waterstof op de zachte materialen in RNB gasdrukregelinstallaties

8 Annex A

This annex is the substantiation of the chosen criterion, stated in 4.1.1

In this GASTEC QA approval requirement are included the requirements for leak tightness. Therefor a distinction has been made between:

- products (e.g. couplings) for which leak tightness is a requirement and
- products (e.g. ball valves and regulators) for which a certain amount of leakage is allowed.

The first type of products, where leak tightness is a requirement, are normally tested in a container with water where no air bubbles may be visible under certain conditions.

For the second type of products, where a certain amount of leakage is allowed, measuring equipment is used, to measure the leakage value in a particular way.

his annex is the substantiation of the chosen criterion, stated in 4.1.1. The conversion factor depends on the flow rate that may cause a laminar or turbulent flow.

A distinction is made between small leaks and large leaks. A small leak causes a laminar flow, a large leak causes a turbulent flow.

On the basis of (part A) the calculated (released) energy for the situation of a large (turbulent) leakage flow of hydrogen and (B) research into the leak tightness requirements of a natural gas network for the situation that hydrogen passes through, it has been reasoned what the leak tightness requirements should be for products which are already certified according to a GASTEC QA approval requirement. .

Part A:
For A the following 3 steps are followed:

- Step 1: Calculation of the volume flow rate
- Step 2: Calculation of the mass flow rate based on the outcome of step 1
- Step 3: Calculation of the energy flow based on the outcome of step 2.

Step 1: The volume flow rate is calculated by using the formula below:

$$Q_v = A \sqrt{\frac{2\Delta P}{\rho}}$$

Whereby:
Q_v = volume flow rate in m^3/s
A = surface in m^2
P = pressure in Pa
ρ = density in kg/m^3 (ρ_{air} = 1 kg/m^3; $\rho_{natural\ gas}$ = 0.83 kg/m^3; $\rho_{hydrogen}$ = 0.09 kg/m^3)

When a turbulent leakage applies, the gas flow ratio (calculated in step 1) of air, natural gas and hydrogen is shown in the table 3, below:

	Air	Natural Gas	Hydrogen
Volume flow rate (m^3/s)	1	1.1	3.3

Table 3

Step 2: By multiplying the volume flow rate (see table 3) by its density, the mass flow of the released gas per second is calculated.

$Q_{m,\ air}$ = 1.0 m^3/s x 1.00 kg/m^3 = 1.000 kg/s
$Q_{m,\ natural\ gas}$ = 1.1 m^3/s x 0.83 kg/m^3 = 0.913 kg/s
$Q_{m,\ hydrogen}$ = 3.3 m^3/s x 0.09 kg/m^3 = 0.297 kg/s

Step 3: The released energy flow when a leakage applies can now be calculated by multiplying the mass flow of the released gas with the specific energy of this gas.

The specific energy of natural gas and hydrogen has the following value:

- Natural gas 50 MJ/kg
- Hydrogen 120 MJ/kg

Multiplying gives the following energy flows:

- Natural gas 50 x 0.90 = 45 MJ/s
- Hydrogen 120 x 0.30 = 36 MJ/s

It is concluded, for turbulent leaks, that:

- the volume flow rate for hydrogen is 3 times higher than that of natural gas
- for an identical leak (where the outlet of the flow is equal) the released energy of hydrogen is lower than for natural gas.

Part B
As far as B is concerned, the following is stated in the HyDelta research study (*HyDelta report: WP 1C Pipes and indoor installations, D1C.2 question number 124 – Tighness of distribution pipes'*) into the requirements for leak tightness of a natural gas network (up to and including 200 mbar) for the situation that hydrogen flows through it:

- From the measured flow ratios at different pressures, it is concluded that the leakage flow of
  - both natural gas and hydrogen at 30 mbar behaves laminar and at
  - hydrogen at 100 and 200 mbar behaves laminar or in the transition area between laminar and turbulent.
- Is has been established that the situation of a huge, turbulent leak, the flow rate with hydrogen increases by a factor of 1.83 compared to natural gas.
- It is assumed that the risks of ignition of a gas-air concentration <8 vol% for hydrogen is lower than for natural gas with a concentration of 5.9 vol%.

The requirements for leak tightness that follow from this HyDelta research study are:

- For new connection pipelines (up to and including 200 mbar), the same leak tightness requirements can be used for hydrogen as for natural gas.
- For existing connecting pipelines (up to and including 200 mbar) the leak tightness requirements shall be more strict. The maximum permissible leakage volume for existing hydrogen connection pipelines is 74% of that for natural gas.

For certification purposes, the more strict leak tightness requirement shall be applied. This means that the maximum permissible leakage rate for hydrogen application, in the natural gas network up to and including 200 mbar, may not exceed 74% of the requirement set for natural gas. [4]

In case of products used in the natural gas network, where pressures higher than 200 mbar apply and where leakage can occur, it is assumed that the leakage flow will be turbulent. The permissible leakage flow rate of hydrogen in this case is 3 times that for natural gas. [4]

Conclusion

From the conclusions of A, assuming the worst case (turbulent flow) and B, the following leak tightness requirements are set for GASTEC QA certified products:

- No additional requirements are imposed on the first* type of product, the leak-tightness of which is tested in a container with water;
- For the second* type of products, a 74% leak-tightness limit applies compared to natural gas;
- In the case of products which are used in the natural gas grid, where pressures higher than 200 mbar apply, it is assumed that the leakage flow is turbulent. The permissible leakage rate of hydrogen in this case is 3 times higher than that for natural gas.

*See paragraphs 2 and 3 of this Annex.

To summarise:

The volume, mass and energy flow rates for an identical leak of air, natural gas and hydrogen are shown in the table 4, below. Also included are the leakage limits:

			Air	Natural gas	Hydrogen
Step 1	Q_v	Volume flow rate (m^3/s)	1	1.1	3.3
Step 2	Q_m	Mass flow rate (kg/s)	1	0.913	0.297
Step 3	Q_e	Energy flow (MJ/s)		45.65	35.64

Leak tightness limit natural gas grid ≤ 200 mbar		1	0.74
Leak tightness limit natural gas grid >200mbar		1	3

Table 4