



BSI Standards Publication

Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — Guidance on hydrogen specific aspects

National foreword

This Published Document is the UK implementation of CEN/TR 17924:2025. It supersedes PD CEN/TR 17924:2023, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/22, Safety and control devices for gas and oil burners and gas burning appliances.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Safety and control devices for burners and appliances burning gaseous and/or liquid fuels - Guidance on hydrogen specific aspects

Dispositifs de sécurité et de contrôle des brûleurs et
des appareils brûlant des combustibles gazeux et/ou
liquides - Orientations concernant les aspects
spécifiques à l'hydrogène

Sicherheits- und Regeleinrichtungen für Brenner und
Brennstoffgeräte für gasförmige und/oder flüssige
Brennstoffe - Leitfaden zu wasserstoffspezifischen
Aspekten

This Technical Report was approved by CEN on 6 January 2025. It has been drawn up by the Technical Committee CEN/TC 58.

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European foreword

This document (CEN/TR 17924:2025) has been prepared by Technical Committee CEN/TC 58 “Safety and control devices for burners and appliances burning gaseous or liquid fuels”, the secretariat of which is held by BSI.

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Introduction

The use of hydrogen as a renewable fuel next to biomethane is seen as a promising alternative to natural gas soon. As soon as the according regulations and standards are in force, the use of hydrogen can be expected on a more regular basis.

For this reason, the heating and combustion business have to provide suitable solutions based on standardized safety, construction, and performance requirements.

This document provides a summary of considerations regarding safety and performance aspects for safety and control devices which will in some cases require further research.

There are research projects on the use of hydrogen admixture with natural gas in various percentages or as hydrogen like the European THyGA project (up to 60 vol.-% hydrogen fluctuating admixtures to natural gas).

Therefore, this document is written in preparation of future revisions of CEN/TC 58 documents and will describe findings pointing at potential changes, give the according research backgrounds and provide literature sources.

This document includes evaluations regarding different gases, comparing their distinctive characteristics, properties, and their impact on the risk assessment for gas appliances. Theoretical evaluations are complemented by laboratory measurements.

For the future implementation of hydrogen in the whole value chain co-operation with other CEN/TCs is necessary like e. g., CEN/TC 234 “Gas infrastructure”, CEN/TC 109 “Central heating boilers using gaseous fuels”, CEN/TC 131 “Gas burners using fans”, and CEN/TC 186 “Industrial thermoprocessing — Safety”.

This document up to Annex A is based on the structure of EN 13611:2019.

In this document only those clauses of EN 13611:2019 are referred to, which can be affected by using hydrogen or hydrogen admixtures as gaseous fuels. All other clauses, which can be not affected, are not listed in this document.

For the calculations and measurements in this document the specific admixture of 20 vol.-% hydrogen and 80 vol.-% methane is used. This admixture is already used as a typical reference in other standards.

1 Scope

This document is written in preparation of future revision of standards dealing with the general safety, design, construction, and performance requirements and testing of safety, control or regulating devices (hereafter referred to as controls) for burners and appliances burning hydrogen (see 3.2) or hydrogen admixtures (see 3.3).

This document refers to controls with declared maximum inlet pressure up to and including 500 kPa and of nominal connection sizes up to and including DN 250.

The purpose of this document is to provide guidance on hydrogen specific topics, which need to be considered in the future standardization of controls covered by CEN/TC 58 documents including:

- automatic shut-off valves;
- automatic burner control systems;
- flame supervision devices;
- gas/air ratio controls;
- pressure regulators;
- manual taps;
- mechanical thermostats;
- multifunctional controls;
- pressure sensing devices;
- valve proving systems;
- automatic vent valves.

Hydrogen will play a significant role in the future in several energy segments and requirements and test methods need to be verified and adapted, if necessary.

The main target of this document is to lay the ground for defining requirements and tests for controls used for safety related functions (e. g., safety valves, automatic burner control systems, gas/air ratio controls) or regulating devices.

Summaries of subclauses to be addressed in the respective standards of each CEN/TC 58 WG are given in

- Annex A: Specific considerations to CEN/TC 58/WG 11 standards,
- Annex B: Specific considerations to CEN/TC 58/WG 12 standards,
- Annex C: Specific considerations to CEN/TC 58/WG 13 standards, and
- Annex D: Specific considerations to CEN/TC 58/WG 14 standards.

Aspects to be included for gas appliances (e. g., boilers, forced draught gas-burners, or industrial thermoprocessing equipment) covering e. g., risk assessment, standardization, certification, and operation are listed in

- Annex E: Risk assessment, standardization, certification, and operation of gas appliances with admixtures fluctuating up to 20 vol.-% hydrogen to natural gas, and

- Annex F: Risk assessment, standardization, certification, and operation of gas appliances using hydrogen referring to ISO 14687:2019, Type I, Grade A.

Proposals for leakage rate requirements and tests for gas pipework including controls (e. g., valves, regulators, pressure switches) used in gas appliances (e. g., forced draught gas-burners or industrial thermoprocessing equipment) and the impact on the installation room size are shown in Annex G.

Considerations to be taken to stay below possible lower explosion limits in gas appliances (e. g., boilers, forced draught gas-burners, or industrial thermoprocessing equipment) and its installation rooms are shown in

- Annex H: Examples of mitigation measures in case of diaphragm fracture or fracture of non-metallic parts for different combustible gases to stay below 25 % of their LEL, based on measurements and calculations, and
- Annex I: Examples of mitigation measures in case of leakages for different combustible gases to stay below 25 % of their LEL, based on measurements and calculations.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13611:2019¹, *Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 13611:2019, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp/>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

lower explosion limit

LEL

lowest concentration of the explosion range at which an explosion can occur

[SOURCE: EN 13237:2012, 3.19.1]

3.2

hydrogen

gaseous hydrogen with a purity of at least Type I, Grade A

Note 1 to entry: Purity limits are given in ISO 14687:2019.

Note 2 to entry: For calculations in this document hydrogen is considered as 100 % H₂.

¹ Impacted by EN 13611:2019/AC:2021² Assumption for calculations for DN > 100

3.3

hydrogen admixture

hydrogen in natural gas fluctuating admixture with an overall hydrogen content from 0 to 100 vol.-%

4 Classification

4.1 Classes of control

In some standards the use of hydrogen can require a categorization based on the used concentration. There will be fluctuations and variation in concentration which will be limited and will be described in future revisions of EN 16726:2015+A1:2018.

There are research and considerations on the use of hydrogen as an admixture with natural gas in various percentages or as hydrogen.

Referring to the scope there is no further need in this document to classify controls with respect to using hydrogen admixtures or hydrogen.

4.2 Classification of hydrogen

Based on literature hydrogen gas properties and purity are:

Table 1 is an extract of PAS 4444:2020 + A1:2021, Table 1:

Table 1 — Hydrogen test gas characteristics — gas dry at 15 °C and 1 013,25 mbar

Gas family	Test gases	Designation	Composition by volume	W_1 MJ/m ³	H_1 MJ/m ³	W_s MJ/m ³	H_s MJ/m ³	d
Gases of the fourth family								
Group Y	Reference gas	G40	H ₂ = 99,9	38,67	10,2	45,88	12,1	0,0696
	Limit gases	To be defined						

Purity report from Hy4Heat:

<https://static1.squarespace.com/static/5b8eae345cfd799896a803f4/t/5e58ebfc9df53f4eb31f7cf8/1582885917781/WP2+Report+final.pdf>

Table 2 is an extract of ISO 14687:2019, Table 1.

Table 3 is an extract of ISO 14687:2019, Table 4.

Table 2 — Hydrogen and hydrogen-based fuel classification by application

Type	Grade	Category	Applications	Clause
I Gas	A	—	Gaseous hydrogen; internal combustion engines for transportation; residential/commercial combustion appliances (e. g., boilers, cookers, and similar applications)	7
	B	—	Gaseous hydrogen; industrial fuel for power generation and heat generation except PEM fuel cell applications	7
	C	—	Gaseous hydrogen; aircraft and space-vehicle ground support systems except PEM fuel cell applications	7
	Da,b	—	Gaseous hydrogen; PEM fuel cells for road vehicles	5
	E		PEM fuel cells for stationary appliances	6
		1	Hydrogen-based fuel; high efficiency/low power applications	
		2	Hydrogen-based fuel; high power applications	
		3	Gaseous hydrogen; high power/high efficiency applications	
a Grade D may be used for other fuel cell applications for transportation including forklifts and other industrial trucks if agreed upon between supplier and customer.				
b Grade D may be used for PEM fuel cell stationary appliances alternative to grade E category 3.				

Table 3 — Fuel quality specification for applications other than PEM fuel cell road vehicle and stationary applications

Constituents	Type I			Type II	Type III
	Grade A	Grade B	Grade C	Grade C	
Hydrogen fuel index ^a (minimum mole fraction, %)	98,0 %	99,90 %	99,995 %	99,995 %	99,995 %
Para-hydrogen (minimum mole fraction, %)	NS	NS	NS	95,0 %	95,0 %
Impurities (maximum content)					
Total gases	20 000 µmol/mol	1 000 µmol/mol	50 µmol/mol	50 µmol/mol	
Water (H ₂ O) (mole fraction, %)	Non-condensing at all ambient conditions ^b	Non-condensing at all ambient conditions	^c	^c	
Total hydrocarbon	100 µmol/mol	Non-condensing at all ambient conditions	^c	^c	
Oxygen (O ₂)	^b	100 µmol/mol	^d	^d	
Argon (Ar)	^b		^d	^d	
Nitrogen (N ₂)	^b	400 µmol/mol	^c	^c	

Constituents	Type I			Type II	Type III
	Grade A	Grade B	Grade C	Grade C	
Helium (He)			39 µmol/mol	39 µmol/mol	
Carbon dioxide (CO ₂)			e	e	
Carbon monoxide (CO)	1 µmol/mol		e	e	
Mercury (Hg)		0,004 µmol/mol			
Sulfur (S)	2,0 µmol/mol	10 µmol/mol			
Permanent particulates	g	f	f	f	
Density					f

NOTE NS: Not specified.

^a The hydrogen fuel index is determined by subtracting the “total non-hydrogen gases” expressed in mole percent, from 100 mol percent.

^b Combined water, oxygen, nitrogen, and argon: maximum mole fraction of 1,9 %.

^c Combined nitrogen, water, and hydrocarbon: max. 9 µmol/mol.

^d Combined oxygen and argon: max. 1 µmol/mol.

^e Total CO₂ and CO: max. 1 µmol/mol.

^f To be agreed between supplier and customer.

^g The hydrogen cannot contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to damage the fuelling station equipment or the vehicle (engine) being fuelled.

EASEE-Gas also published a common business practice about the hydrogen quality specification for dedicated hydrogen pipelines. Link: <https://easee-gas.eu/latest-cbps>

Furthermore, a CEN/TS 17977 for the quality of hydrogen used in converted/rededicated gas systems is available, which is proposing a minimum hydrogen concentration of 98 mol-% within certain maximum impurity concentrations.

5 Common properties

The intention of this document is to enable the use of the controls with hydrogen and hydrogen admixtures. Controls are already used with several fuels like biomethane or natural gas. Therefore, it is reasonable to summarize the properties of different common fuels like methane (natural gas), propane, and butane in comparison to a specific hydrogen admixture and hydrogen. Based on similarities and differences further conclusions, consequences, risk assessments, and impacts on materials are derived in this document.

Table 4 summarizes the properties of air (as common reference), methane (natural gas), propane, butane, hydrogen, and 20 vol.-% hydrogen/80 vol.-% methane admixtures.

Table 4 — Gas properties

properties	unit	air	methane (CH ₄)	propane (C ₃ H ₈)	butane (isobu- tane) (C ₄ H ₁₀)	hydro- gen (H ₂)	20 vol.-% H ₂ /80 vol.-% CH ₄ admixture
lower explosion limit LEL (20 °C)	[%]	—	4,4 ^a	1,7 ^a	1,3 ^a	4,0 ^a	4,2 ^b
flammability temperature (air)	[°C]	—	595 ^a	445 ^a	460 ^a	560 ^a	588 ^c
density ρ_{gas} (at 15 °C)	[kg/m ³]	1,220 ^d	0,680 ^d	1,893 ^d	2,527 ^d	0,084 ^d	0,560 ^d
relative density d_v related to air	—	1	0,555 ^e	1,550 ^e	2,075 ^e	0,069 ^d	0,457 ^d
dynamic viscosity η (at 15 °C)	[Pa·s]	17,97 E- 6 ^d	10,87 E- 6 ^d	7,95 E-6 ^d	7,32 E-6 ^d	8,65 E-6 ^d	10,98 E-6 ^f
minimum air supply AS	[m ³ air]/[m ³ gas]	—	9,52 ^g	23,80 ^g	30,94 ^g	2,38 ^g	8,12 ^c
calorific value H_i (inferior) (at 15 °C; 101,3 kPa)	[MJ/m ³]	—	34,02 ^e	88,00 ^e	116,09 ^e	10,22 ^g	29,27 ^c
calorific value H_s (superior) (at 15 °C; 101,3 kPa)	[MJ/m ³]	—	37,78 ^e	95,65 ^e	125,81 ^e	11,97 ^d	32,56 ^d
Wobbe Index W_i (inferior)	[MJ/m ³]	—	45,67 ^e	70,69 ^e	80,58 ^e	38,62 ^d	43,24 ^d
Wobbe Index W_s (superior)	[MJ/m ³]	—	50,72 ^e	76,84 ^e	87,33 ^e	45,65 ^d	48,20 ^d
Source: ^a IEC 80079-20-1:2017 “Explosive atmospheres — Part 20-1: Material characteristics for gas and vapour classification — Test methods and data” ^b Scholten Dörr Wersky “Mögliche Beeinflussung von Bauteilen der Gasinstallation bei Wasserstoffanwendungen” ^c Calculation by CEN/TC 58 WG 15/PG 1, 2022-02 ^d VDI-Wärmeatlas: 2013. 11 th edition ^e EN 437:2021 ^f Mason, E.A., and S. C. Saxena: The Physics of Fluids, Volume 1, Number 5 (1958), pp. 361; and C. R. Wilke: The Journal of Chemical Fluids, Volume 18, Number 4 (1950), pp. 517 ^g Günter Cerbe: “Grundlagen der Gastechnik — Gasbeschaffung — Gasverteilung — Gasverwendung”							

Based on the common properties and measurements the following aspects demand further considerations with respect to subclauses of EN 13611:2019:

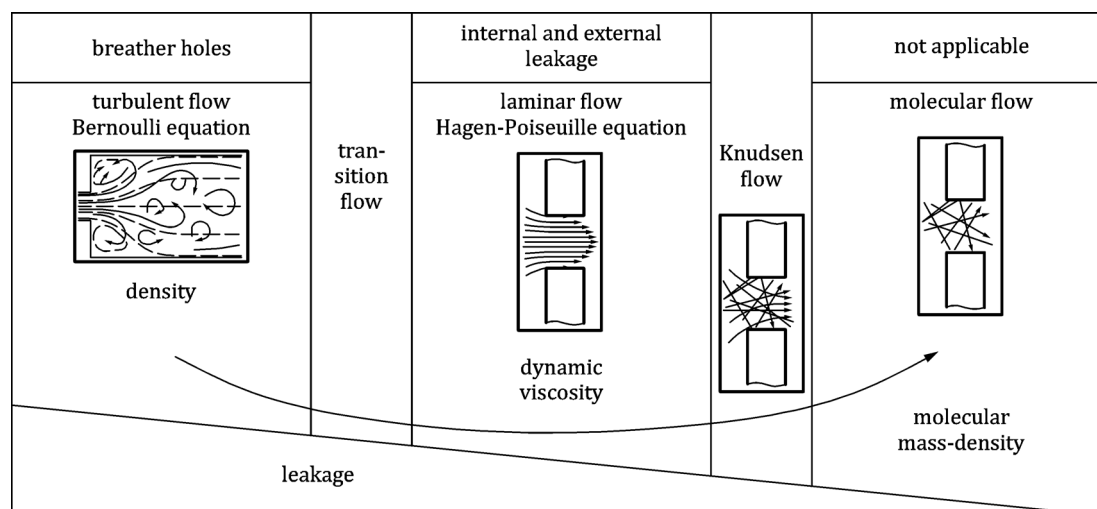
- a) leak-tightness — see 7.1
- b) breather holes and housings — see 6.1.3 and 6.2.2
- c) materials — see 6.2
- d) safety aspects (risk assessment — see Annexes E and F)

6 General considerations regarding design and construction

6.1 Mechanical parts of the control

NOTE 6.1 refers to EN 13611:2019, 6.2.

6.1.1 Theoretical background



To avoid too much damping on the regulator, breather holes need to have a certain minimum size. That is, the flow can turn from laminar to turbulent, because breather hole sizes are bigger than internal/external leakage hole sizes.

Figure 1 — Leakage models by theory

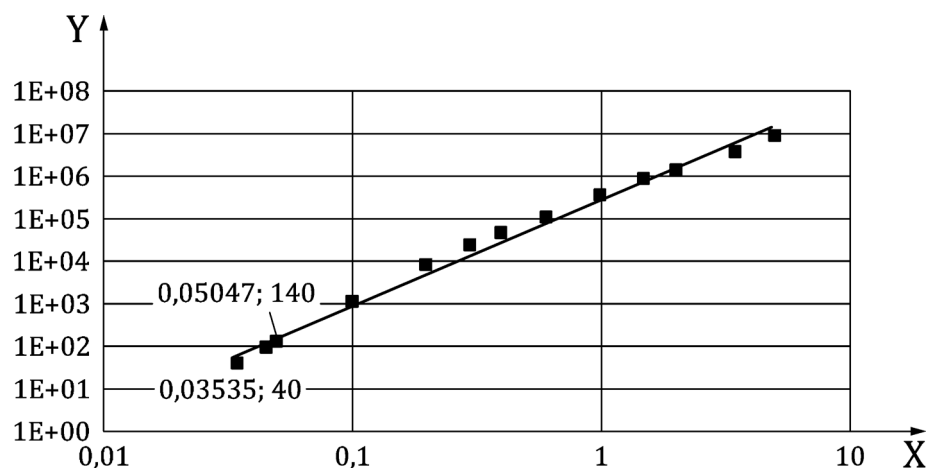
Figure 1 summarizes the flow characteristics which need to be taken into consideration if leakage of gaseous fuel is to be expected.

Depending on the design and the leakage rate a molecular, laminar, or turbulent flow of the gaseous fuel is differentiated.

Based on the common configuration of a control a molecular flow can be excluded.

Calculations in the area between a molecular and laminar flow showed that the “Knudsen flow” is not relevant (see also Figure 2).

NOTE Information regarding the modified Knudsen equation for transitional flow (between molecular and laminar) can be found in EN ISO 12807:2021, Annex B. Practical maximum leakage rates for molecular flow and minimum leakage rates for viscous laminar flow can be found in EN 1779:1999+A1:2004, 7.3.

**Key**

- X pinhole diameter (mm)
 Y air flow rate (cm³/h)

Figure 2 — Pinhole calculations derived from leakage rate measurements at $\Delta p = 15$ kPa

Justification that Knudsen flow is not applicable is supported by calculation results.

Very small pinholes are needed for EN 13611:2019 and EN 15502-1:2021 limits:

- $\sim 35 \mu\text{m}$ for $40 \text{ cm}^3/\text{h}$ at $\Delta p = 15 \text{ kPa}$ air;
- $\sim 50 \mu\text{m}$ for $140 \text{ cm}^3/\text{h}$ at $\Delta p = 15 \text{ kPa}$ air.

Calculation with Knudsen number:

The diameter of a pinhole leakage rate needs to be:

- $< 230 \text{ nm}$ for pure molecular flow type;
- $> 11,5 \mu\text{m}$ for pure laminar flow type.

Conclusion: $35 \mu\text{m} > 11,5 \mu\text{m}$, therefore, molecular flow and Knudsen flow is not relevant.

The internal and external leakage rates are limited by the CEN/TC 58 and CEN/TC 109 standards. A summary of these values is given in Table 5. Based on the design of the control (the leakage path is assumed to have a greater length than cross-section) a laminar flow was confirmed by measurements.

For breather holes, where the leakage rate limit value in case of fracture of a diaphragm is $70 \text{ dm}^3/\text{h}$ of air, and for housings, where the leakage rate limit value in case of fracture of non-metallic parts is $30 \text{ dm}^3/\text{h}$ of air, referring to the model given in 6.1.3.2 turbulent flow was confirmed.

Table 5 — Summary of internal and external leakage rate requirements in current standard editions

Parameter Test criteria Unit	Nominal inlet size	Internal leakage rate at $1,5 \cdot p_{\max}/\text{minimum}$ 15 kPa	External leakage rate at $1,5 \cdot p_{\max}/\text{minimum}$ 15 kPa
		[cm ³ /h]	[cm ³ /h]
EN 13611:2019, <i>Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements</i>	DN < 10	≤ 20	≤ 20
	10 ≤ DN ≤ 25	≤ 40	≤ 40
	25 < DN ≤ 80	≤ 60	≤ 60
	80 < DN ≤ 150	≤ 100	
	150 < DN ≤ 250	≤ 150	
EN 126:2012, <i>Multifunctional controls for gas burning appliances</i>	DN < 10	EN 13611:2019	≤ 60
	10 ≤ DN	EN 13611:2019	≤ 120
EN 161:2022, EN 88-1:2022, EN 88-2:2022, EN 88-3:2022, and EN 1854:2022 refer to the requirements and tests of EN 13611:2019.			
EN 15502-1:2021, <i>Gas-fired heating boilers — Part 1: General requirements and tests</i>	—	—	≤ 140 (at 5 kPa or 15 kPa only)

6.1.2 Holes

NOTE 6.1.2 refers to EN 13611:2019, 6.2.2.

There are no specific considerations to holes.

6.1.3 Breather holes

NOTE 6.1.3 refers to EN 13611:2019, 6.2.3.

6.1.3.1 Alternative requirements for breather holes

For breather holes the leakage rate limit values in case of diaphragm fracture is 70 dm³/h of air, and turbulent flow was confirmed by measurements.

In case of transition flow, where the flow rates are between the values of

- laminar flow referring to the flow model in 7.1.1, and
- turbulent flow referring to the flow model in 6.1.3.2,

the leakage rate limit values are to be calculated referring to the turbulent flow model as given in 6.1.3.2. This covers the higher leakage rate values to stay on the safe side.

Table 6 shows the breather hole and housing leakage rate limits (referring to air as test gas), which are only to be considered if a diaphragm fracture or fracture of non-metallic parts is assumed as failure, and the possibility to use an alternative requirement and test.

Table 6 — Breather hole and housings leakage rates referring to air as test gas

Parameter Test criteria Unit	Scope limit of standards $p_{\max}$ [kPa]	Housing at $p_{\max}$ [dm ³ /h]	Breather hole at $p_{\max}$ [dm ³ /h]
EN 13611:2019: General	up to and including 500	30	70
EN 126:2012: Multifunctional controls	up to and including 50	—	—
EN 161:2022: Automatic shut-off valves	up to and including 500	EN 13611:2019	—
EN 88-1:2022: Pressure regulators, pneumatic type	up to and including 50	EN 13611:2019	EN 13611:2019 or alternative requirement and test
EN 88-2:2022: Pressure regulators, pneumatic type	above 50 up to and including 500	EN 13611:2019	EN 13611:2019
EN 88-3:2022: Pressure regulators, electronic type	up to and including 500	EN 13611:2019	EN 13611:2019 or alternative requirement and test
EN 1854:2022: Pressure sensing devices	up to and including 500	EN 13611:2019 or alternative requirement and test	EN 13611:2019 or alternative requirement and test

If all controls used in applications fulfil the modifications and additions described in

- EN 88-1:2022, 6.2.3, or
- EN 88-3:2022, 6.2.3, or
- EN 1854:2022, 6.2.3 and 6.3.2,

the leakage rate limits and tests are the same as given in Table 5.

Modifications and additions for leakage rates are described in EN 88-1:2022, 6.2.3, EN 88-3:2022, 6.2.3 or EN 1854:2022, 6.2.3 and 6.3.2. In instances where all controls used in applications fulfil these modifications and additions in any of these documents, see Table 5.

In this case there is **no need** to apply the considerations given in 6.1.3.2 to 6.1.3.5 concerning breather holes.

6.1.3.2 Turbulent flow model and calculations

For a turbulent flow characteristic, the Bernoulli equation is applicable:

$$\Delta p = \xi \times \frac{\rho_i}{2} \left(\frac{\dot{V}_{\text{leak},i}}{A_{\text{leak}}} \right)^2$$

where

Δp is the pressure difference between two pressure zones;

ξ is the pressure drop coefficient;

ρ is the density of the gas;

i is the type of gas;

$\dot{V}_{\text{leak}}$ is the volume flow rate of the leak;

A_{leak} is the dimension of the leak.

This leads to:

$$\dot{V}_{\text{gas,leak},i} = \frac{\dot{V}_{\text{air,leak}}}{\sqrt{d_{V,\text{gas},i}}}$$

where

d_V is the relative density (see Table 4).

Table 7 shows the calculation of leakage rates referring to the turbulent flow model.

Table 7 — Calculation of leakage rates and their relation to different combustible gases in case of diaphragm fracture or fracture of non-metallic housing parts (turbulent flow)

	air	me- thane (CH ₄)	pro- pane (C ₃ H ₈)	butane (C ₄ H ₁₀)	hy- dro- gen (H ₂)	20 vol.-% H ₂ /80 vol.-% CH ₄ admixture
density ρ_{gas} at 15 °C [kg/m ³]	1,220	0,680	1,893	2,527	0,084	0,560
volume flow rate factor related to air $= \sqrt{\frac{\rho_{\text{air}}}{\rho_{\text{gas}}}}$	1,0	1,34	0,80	0,69	3,81	1,48
volume flow rate factor related to methane $= \sqrt{\frac{\rho_{\text{methane}}}{\rho_{\text{gas}}}}$	—	1,0	0,60	0,52	2,85	1,10
lower explosion limit (LEL) [%]	—	4,4	1,7	1,3	4,0	4,2
LEL factor considered as an additional factor $= \frac{\text{LEL}_{\text{methane}}}{\text{LEL}_{\text{gas}}}$	—	1,0	2,59	3,38	1,10	1,05
gas leakage rate factor related to methane for different gases to stay below their LEL $= 1 / \left(\sqrt{\frac{\rho_{\text{methane}}}{\rho_{\text{gas}}}} \cdot \frac{\text{LEL}_{\text{methane}}}{\text{LEL}_{\text{gas}}} \right)$	—	1,0	0,64	0,57	0,32	0,87
related to methane, the limit values for leakage rates measured with air for different gases to stay below their LEL is reduced by (see Table 6):	—	—	36 %	43 %	68 %	13 %

NOTE The values do not consider the result of application risk assessments, which can lead to lower leakage rates.

The gas density ρ and its LEL determine the risk level under turbulent flow conditions (e. g. for hydrogen the leakage rate is reduced by 68 % to achieve the same risk level as for methane).

6.1.3.3 Leakage rate measurements and calculations

Leakage rates of different test leaks, sized for 1 dm³/h, 30 dm³/h, and 70 dm³/h air leakage rate at design pressures of each Δp of 6 kPa, 15 kPa, 50 kPa, 100 kPa, and 500 kPa, were measured from 6 kPa up to 500 kPa with air, methane, hydrogen, and 20 vol.-% hydrogen/80 vol.-% methane admixture (see Table 8). The test leak design pressures are chosen referring to typical used pressure limits in applications and EN 13611:2019, EN 88-1:2022, EN 88-2:2022, EN 88-3:2022, and EN 1854:2022.

Table 8 — Test leaks and their design pressures

test leak designation	air leakage rate [dm ³ /h]	design pressures [kPa]	test media
A.3.1, A.3.2, A.3.3, A.3.4, A.3.5	1	6, 15, 50, 100, 500	air, hydrogen, methane, 20 vol.-% hydrogen/80 vol.-% methane admixture
A.4.1, A.4.2, A.4.3, A.4.4, A.4.5	30	6, 15, 50, 100, 500	air, hydrogen, methane, 20 vol.-% hydrogen/80 vol.-% methane admixture
A.5.1, A.5.2, A.5.3, A.5.4, A.5.5	70	6, 15, 50, 100, 500	air, hydrogen, methane, 20 vol.-% hydrogen/80 vol.-% methane admixture

Measurement results are dependent on the size of the test leak: test leaks of the same leakage rate designed at a Δp of e. g. 6 kPa and 500 kPa have different leakage rate ratios with respect to air and methane. Therefore, each maximum measurement and worst-case ratio values are listed in Table 9 to Table 12, columns measurement.

In case of test leak size 1 dm³/h the Reynold's numbers calculated from measurements are much lower than 2.300 indicating laminar flow referring to the Hagen-Poiseuille equation. In all other cases the Reynold's numbers calculated from measurements are much higher than 2.300 indicating turbulent flow referring to the Bernoulli equation.

Table 9 — Measurements and calculations of leakage rate ratios for different combustible gases, related to methane, in case of diaphragm fracture (70 dm³/h air leakage rate)

combustible gas	column M1: breather hole gas leakage rate <i>BGL</i> to be considered based on maximum measured values column C1: calculations rounded to the worst case [dm ³ /h]		column M3: time to reach 1 m ³ methane emitted based on maximum measured values column C3: calculations rounded to the worst case [h]		column M5: time to reach 25 % of the LEL of methane emitted in a volume of 1 m ³ based on maximum measured values column C5: calculations rounded to the worst case [h]		column M7: minimum required air exchange flow rate <i>BAC_{min}</i> for methane emitted to stay below 25 % of its LEL in a volume of 1 m ³ based on maximum measured values column C7: calculations rounded to the worst case [m ³ /h]	
	at 70 dm ³ /h air		at 70 dm ³ /h air		at 70 dm ³ /h air		at 70 dm ³ /h air	
	M1	C1	M3	C3	M5	C5	M7	C7
methane (CH ₄)	108,3	94	9,2	10,6	0,10	0,11	9,85	8,55
combustible gas ratios compared to values of methane above	column M2: ratio calculations rounded to the worst case of breather hole gas leakage rate ratios to be considered based on maximum measured values column C2: calculations rounded to the worst case [-]		column M4: ratio calculations rounded to the worst case of time ratios to be considered to reach 1 m ³ emitted gas based on maximum measured values column C4: calculations rounded to the worst case [-]		column M6: ratio calculations rounded to the worst case of time ratios to be considered to reach 25 % of the LEL of the emitted gas in a volume of 1 m ³ based on maximum measured values column C6: calculations rounded to the worst case [-]		column M8: ratio calculations rounded to the worst case of minimum required air exchange rate ratios to be considered to stay below 25 % of the LEL of the emitted gas in a volume of 1 m ³ based on maximum measured values column C8: calculations rounded to the worst case [-]	
	M2	C2	M4	C4	M6	C6	M8	C8
propane (C ₃ H ₈)/methane	no data available	0,60	no data available	1,67	no data available	0,645	no data available	1,55
butane (C ₄ H ₁₀)/methane	no data available	0,52	no data available	1,93	no data available	0,570	no data available	1,76
hydrogen (H ₂)/methane	2,74	2,93	0,36	0,34	0,32	0,30	3,05	3,23
20 vol.-% hydrogen/ 80 vol.-% methane admixture	1,11	1,10	0,90	0,91	0,85	0,86	1,16	1,15

6.1.3.4 Conclusions on leakage rate measurements and calculations in case of diaphragm fracture

The conclusions based on the flow rate calculations and laboratory measurements are:

- measurements confirmed a turbulent flow referring to the Bernoulli equation;
- the measured and calculated values for hydrogen are about 3 times higher than the limit values for methane;
- for 20 vol.-% hydrogen/80 vol.-% methane admixtures the values are about 10 % higher.

The requirement stays at 70 dm³/h, and a risk assessment for the application in the real foreseeable use is conducted. Examples are given in 6.1.3.5.

The higher leakage rate values for propane and butane need to be considered (see Table 7) in the risk assessment of appliances.

6.1.3.5 Considerations based on a risk assessment

6.1.3.5.1 Design – failure mode conditions

The existing design configurations have been reviewed under failure mode conditions as shown in Figure 3. Under these configurations a leakage to the environment would be possible and would lead to the following consequences.



a) Gas circuit pressurized during operation only (configuration A)

Under a failure two different leakage scenarios occur:

- A.1 Damage of a diaphragm with one closed upstream gas safety shut-off valve → no leakage
- A.2 Damage of a diaphragm with open upstream gas safety shut-off valve → leakage to environment and flow to combustion chamber

b) Gas circuit pressurized permanently (configuration B)

Under a failure two different leakage scenarios occur:

- B.1 Damage of a diaphragm → leakage to environment
- B.2 Damage of a diaphragm with open downstream gas safety shut-off valve → leakage to environment and flow to combustion chamber

Key

V automatic shut-off valve (EN 161:2022)

M non-metallic housing part (EN 13611:2019)

R regulator, where a diaphragm rupture leads to external or internal leakage (EN 88-1:2022, EN 88-2:2022, EN 88-3:2022)

S pressure sensing device (EN 1854:2022)

Figure 3 — Example of risk scenarios in case of diaphragm fracture

Since in case of diaphragm fracture or fracture of non-metallic parts a certain amount of gas can leak to the environment (see Table 8 and Table 15), it is important to consider the accumulated gas within a defined room volume and time. Therefore, the LEL values of each combustible gas are considered.

Two scenarios for different combustible gases are considered:

- calculation of minimum required air exchange rate $BAC_{\min}$ in case of diaphragm fracture or fracture of non-metallic parts for different combustible gases to stay below 25 % of their LEL at certain leakage rate limits (see Table 10);
- calculation of minimum required room volume $BV_{\min}$ in case of diaphragm fracture or fracture of non-metallic parts at a typical air exchange rate of 0,3 1/h for different combustible gases to stay below 25 % of their LEL at certain leakage rate limits (see Table 11).

Table 10 — Worst-case calculations of minimum required breather hole air exchange flow rates BAC_{min} for different combustible gases to stay below 25 % of their LEL at certain leakage rate limits

leakage rate with air [dm ³ /h]	combustible gas	column M1: breather hole gas leakage rate BGL to be considered based on maximum measured values column C1: calculations rounded to the worst case with Hagen-Poiseuille (laminar flow @ 1 dm ³ /h) and Bernoulli (turbulent flow) [dm ³ /h]		column M2: time to reach 1 m ³ of the gas emitted based on maximum measured values column C2: calculations rounded to the worst case [h]		column M3: time to reach 25 % of the LEL of the emitted gas in a volume of 1 m ³ based on maximum measured values column C3: calculations rounded to the worst case [h]		column M4: minimum required air exchange flow rate BAC_{min} for the emitted gas to stay below 25 % of its LEL in a volume of 1 m ³ based on maximum measured values column C4: calculations rounded to the worst case [m ³ /h]	
		M1	C1	M2	C2	M3	C3	M4	C4
1	methane (CH ₄)	1,65	1,65	606	606	6,6	6,6	0,15	0,15
	propane (C ₃ H ₈)	—	2,26	—	442	—	1,8	—	0,53
	butane (C ₄ H ₁₀)	—	2,45	—	408	—	1,3	—	0,75
	hydrogen (H ₂)	3,59	2,08	278	480	2,7	4,8	0,36	0,2
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	1,71	1,64	584	609	6,1	6,4	0,16	0,15
30	methane (CH ₄)	40,3	40	24,8	25	0,27	0,27	3,67	3,63
	propane (C ₃ H ₈)	—	24	—	42	—	0,17	—	5,67
	butane (C ₄ H ₁₀)	—	21	—	48	—	0,15	—	6,41
	hydrogen (H ₂)	102,3	114	9,7	8,7	0,09	0,08	10,31	11,49
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	41,6	44	24	22,7	0,25	0,23	3,96	4,20
70	methane (CH ₄)	108,3	94	9,2	10,6	0,10	0,11	9,9	8,6
	propane (C ₃ H ₈)	—	56	—	18	—	0,07	—	13,2
	butane (C ₄ H ₁₀)	—	49	—	21	—	0,06	—	15
	hydrogen (H ₂)	238	267	4,2	3,7	0,04	0,03	23,8	27
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	110,6	103	9	9,7	0,09	0,1	10,6	9,8

For Table 10 the worst-case approach consists of:

- no air exchange;
- appliance is in stand-by → only external leakage rate is considered for a gas circuit under permanent pressure;
- internal leakage rate is not connected to the room and therefore of no concern.

For each combustible gas, the time to reach 25 % of its LEL in a certain room volume can be calculated.

Also, for each combustible gas the minimum required breather hole air exchange rate $BAC_{\min}$ to stay below 25 % of its LEL can be calculated ($\sim 1/\text{room size}$).

Table 11 — Measurements and calculations of minimum required room volumes $BV_{\min}$ at a typical air exchange rate of 0,3 1/h for different combustible gases to stay below 25 % of their LEL at certain leakage rate limits

breather hole leakage rate with air [dm ³ /h]	combustible gas	column M1: breather hole gas leakage rate BGL to be considered based on maximum measured values column C1: calculations rounded to the worst case with Hagen-Poiseuille (laminar flow @ 1 dm ³ /h) and Bernoulli (turbulent flow) [dm ³ /h]		column M2: minimum required air exchange flow rate $BAC_{\min}$ for the emitted gas to stay below 25 % of its LEL in a volume of 1 m ³ based on maximum measured values column C2: calculations rounded to the worst case [m ³ /h]		column M3: minimum required volume $BV_{\min}$ for the emitted gas to stay below 25 % of its LEL based on maximum measured values column C3: calculations rounded to the worst case [m ³]	
		M1	C1	M2	C2	M3	C3
1	methane (CH ₄)	1,65	1,65	0,15	0,15	0,50	0,50
	propane (C ₃ H ₈)	—	2,26	—	0,53	—	1,77
	butane (C ₄ H ₁₀)	—	2,45	—	0,75	—	2,50
	hydrogen (H ₂)	3,59	2,08	0,36	0,2	1,20	0,67
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	1,71	1,64	0,16	0,15	0,53	0,50
30	methane (CH ₄)	40,3	40	3,67	3,63	12,2	12,1
	propane (C ₃ H ₈)	—	24	—	5,67	—	18,9
	butane (C ₄ H ₁₀)	—	21	—	6,41	—	21,4
	hydrogen (H ₂)	102,3	114	10,31	11,49	34,4	38,3
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	41,6	44	3,96	4,20	13,2	14,0
70	methane (CH ₄)	108,3	94	9,9	8,6	33,0	28,7
	propane (C ₃ H ₈)	—	56	—	13,2	—	44,0
	butane (C ₄ H ₁₀)	—	49	—	15	—	50,0
	hydrogen (H ₂)	238	267	23,8	27	79,3	90,0
	20 vol.-% H ₂ / 80 vol.-% CH ₄ admixture	110,6	103	10,6	9,8	35,3	32,7

For a laminar flow characteristic, the Hagen-Poiseuille equation is applicable:

$$\dot{V}_{\text{leak},i} = \frac{dV_{\text{leak},i}}{dt} = \frac{\pi \cdot r^4}{8 \cdot \eta_i} \frac{\Delta p}{l}$$

where

- $\dot{V}_{\text{leak}}$ is the volumetric flow rate of the leak;
- i is the type of the gas;
- r is the radius of the gap;
- Δp is the pressure difference between two pressure zones;
- η is the dynamic viscosity of the gas (see Table 4);
- l is the length of the gap.

Table 11 shows the calculation for the breather hole size of 1 dm³/h, where a Reynold's number of less than 2.300 is applicable.

The gas leakage rate BGL_{gas} caused by diaphragm fracture or fracture of non-metallic parts is calculated based on the Bernoulli equation (turbulent flow, which was confirmed by measurements).

$$BGL_{\text{gas}} = A \cdot \sqrt{\frac{\rho_{\text{air}}}{\rho_{\text{gas}}}}$$

where

- A is the leakage rate with air;
- $\rho_{\text{air}}, \rho_{\text{gas}}$ are the different gas densities.

The minimum required air exchange rate BAC_{min} is

$$BAC_{\text{min}} = \frac{BGL_{\text{gas}}}{S \cdot LEL_{\text{gas}}}$$

The minimum required volume BV_{min} is

$$BV_{\text{min}} = \frac{BAC_{\text{min}}}{\text{typical air exchange rate}}$$

6.1.3.5.2 Application specific requirements in case of diaphragm fracture

Another risk approach in case of diaphragm fracture can be derived by calculating a minimum required dilution to stay below 25 % of the LEL of combustible gases, once with methane and once with propane as reference gas (see Table 12).