HyDelta

WP 1C Pipes and indoor installations (components)

D1C.2 question 124 – Tightness of distribution pipes

Status: final

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Corresponding author

Corresponding author	Sander Lueb
On behalf of	Kiwa Technology B.V.
E-mail address	sander.lueb@kiwa.com

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Document assessment

Partner	Name
Kiwa Technology	Peter Postma
Stedin	Dick Nieuwenhuizen
Rendo	Johan Jonkman
Alliander	Rob Nispeling
Enexis	Walter Koppenol
NEC, Kiwa, DNV, TNO, NBNL, Stedin, Alliander	HyDelta Supervisory Group

Summary

As part of the national research programme HyDelta, an investigative study was carried out into tightness criteria for connecting pipelines if they are operated with hydrogen.
The study as described in this report is part of work package 1C "Pipes and Indoor Installations" and concerns research question 124. This is as follows[1] :

- Do the leak tightness requirements for a natural gas network also apply to a network operated with hydrogen?
- If this is not the case, what should the criteria be?

The focus in this study is on service lines. The small leaks that need to be simulated (5 l/h on the basis of air) in main pipelines are so small (the route of the main pipeline is more extensive compared to a connecting pipe) that they will not lead to issues when hydrogen is used. Such minor leaks will not enter buildings, but will evaporate into the open air.

The following activities were carried out with the aim of answering the above question:

- The leakage flow rates were measured at pressures of 30, 100 and 200 mbar with the media nitrogen, natural gas and hydrogen in four leaks that were created on purpose in connecting pipes with a nitrogen content of approximately 1 l/h. The ratios of the leakage flow rates were determined from these results.
- A theoretical consideration has been drawn up for assessing the risks of small hydrogen leaks using the maximum permissible leaks in NEN 7244-7 and the findings from the DNV GL report on the behaviour of hydrogen in leaks in the gas distribution network.
- The measurement results were reviewed in further detail and analysed, and subsequently combined with the theoretical risk assessment.

The conclusions from this study are as follows:
For new service lines, the same tightness requirements can be used for hydrogen as for natural gas. There is no reason to make the criteria more stringent.
For existing connecting pipes, the tightness requirements must be made more stringent. The maximum permissible leakage rate for existing hydrogen service pipelines is 74% of that for natural gas. This has been determined on the basis of the following:

- The measured values give a factor of 1.83 higher leakage for hydrogen
- The assumption 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%

These tightness requirements can be incorporated by extending NEN 7244-7, table 4 for hydrogen, which would then read as follows

[1] The original question as described in the work package description is: Conduct research into the implementation of strength and tightness tests. In consultation with the guidance group and sparring group, the research question has been reformulated.

Maximum leak size at a test pressure equal to MOP		
Type of pipe	**Natural gas Max. leak rate [dm³/h]**	**Hydrogen Max. leak rate [dm³/h]**
Main pipeline	5.0	5.0
Service pipeline - new*	0.2	0.2
Service pipeline - existing	1.0	0.7
Meter set-up	0.1	0.1
*A new pipeline may not leak unnecessarily as a result of installation errors or material faults. The maximum leakage rate of 0.2 l/h is feasible in practice and is therefore regarded as desirable for new connecting pipes. (Feasible in practice based on small allowable leaks from new components and varying measurement conditions). These requirements are the same for hydrogen and natural gas. This also applies to the meter set-up.		

The leak tightness tests for a hydrogen network can be carried out by extending the following sentence (*in italics*) in VWI G-12:

An existing connecting pipe is considered leak tight if the test pressure drops ≤ 5 mbar during an overpressure measurement (at a constant temperature) (*for hydrogen pipes: ≤ 4 mbar*)

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1. Reason

1.1 General

This study has been carried out within the framework of the HyDelta national research programme. The programme focuses on integrating hydrogen safely into the existing gas transport and distribution infrastructure and aims to remove barriers that are hampering innovative hydrogen projects. The complete research programme is divided into work packages. For a detailed explanation of the separate work packages, please visit www.hydelta.nl

1.2 The problem definition

When performing pipe tightness tests on new pipeline networks, the medium generally used to do this is air. The procedure for these tests is described in the NEN 7244-7 standard. This standard also describes the maximum permissible leakage volume for new and existing pipelines, which has proved adequate for natural gas in practice. The question still remains whether the criteria used in those leak tightness test also apply to a network that is operated with hydrogen.

1.3 Research question 124

This report provides answers to research question 124 from the Work Package 1C Pipes and Indoor Installations[2].

The research questions are as follows[3]:

- Do the leak tightness requirements for a natural gas network also apply to a network operated with hydrogen?
- If this is not the case, what should the criteria be?

[2] The other questions from this work package are included in Appendix I.

[3] The original question as described in the work package description is: Conduct research into the implementation of strength and density tests. In consultation with the guidance group and sparring group, the research question has been reformulated. A strength test is performed before commissioning new pipe networks. This test is carried out with air, inert gas or water in accordance with NEN 7244-7. The strength test can also be applied in the same way when commissioning a newly constructed pipeline network that is intended for use with hydrogen. For that reason, this investigation focuses only on the tightness tests.

2. Objective

The aim of this study is to determine whether the same leak tightness requirements that apply to a natural gas network also apply to a network operated with hydrogen. If not, it needs to be determined what the tightness criteria should be.

3. Method

3.1 General work method

The implementation of this study was coordinated with an Expert and Assessment Group consisting of participants from the network operators (see Appendix II).

It is a proven fact that a specific leak opening with the medium of hydrogen will lead to a larger leakage flow rate compared to the same leak opening through which natural gas escapes. This study determined exactly how much larger this leakage flow rate will be for small leaks in connecting pipes. The results are presented in chapter 5.
In addition, it is important to know what the acceptable leakage flow rate is for hydrogen. This mainly theoretical consideration is included in chapter 4.

Chapter 6 combines the results of the measurements and the outcome of the theoretical consideration into a multiplication factor in order to determine the leak tightness criteria for hydrogen.

Originally, the idea was to carry out only leak tightness measurements in the context of this sub-question in order to determine a correction factor for establishing leak tightness criteria when using hydrogen.
Below are some other important principles when carrying out the measurements.

3.2 Scope of the study

The scope of the study is as follows:

- The focus is on connecting pipes. The small leaks that need to be simulated (5 l/h on the basis of air) in main pipelines are so small (the route of the main pipeline is more extensive compared to a connecting pipe) that they will not lead to issues when hydrogen is used. Such minor leaks will not enter buildings, but will evaporate into the open air. Assuming a worst case with a turbulent leak, a leakage size of 5 l/h of nitrogen or air corresponds to a natural gas leakage of approximately 6.2 l/h and a maximum hydrogen leakage of 18.5 l/h. (For a laminar leak, a natural gas flow rate of 7.7 l/h and a hydrogen flow rate of 10 l/h corresponds to a 5 l/h air leak).
- Leaks at couplings in connecting pipes
  Four commonly used couplings in connecting pipes were tested, where a leak was made in order to simulate the outflow of gas through each of the couplings.
- Leakage rate ≈ 1 l/h
  Only measurements in the context of existing connecting pipes and based on a leakage rate of approximately 1 litre per hour of air (nitrogen was used in the measurements, which has virtually the same flow characteristics as air; NEN 7244-7 prescribes air or inert gas).
- Applied pressures
  Hydrogen networks will mainly be operated at 100 mbar, but because pressures of 30 mbar and 200 mbar can also occur, these pressures have been included in the research.

3.3 Test programme measurements

The tests were carried out with four different couplings that are frequently used in connecting pipes. For the purpose of the tests, leaks were made in the following elements:
1) transition coupling of PE-steel;
2) clamp-screw coupling at the transition from saddle tee piece to connecting pipe;
3) sealing ring between saddle and main pipe;
4) coupling of a gas meter inlet valve.

Two different leakage sizes were made for each type of coupling (see Appendix V for a description of how the leaks were applied): leaks were made to create a leak rate of approximately 1 litre per hour of nitrogen at 30 mbar and a leak rate of approximately 1 litre per hour of nitrogen at 100 mbar. The leak of 1 l/h of nitrogen at 30 mbar was tested at a pressure of 100 mbar for three of the four types of couplings (coupling numbers 2, 3 and 4). The leak set-up for 1 l/h of air at 100 mbar was tested at pressures of 30 and 200 mbar. Every leak was tested with nitrogen[4], natural gas and hydrogen.

The leaks were built into a test set-up with a capacity of more than 8 litres. See Appendix IV *Detailed* drawings of the test set-ups for a representation of the test set-ups.

The leakage rate was determined according to the pressure drop over a period of approximately 1 minute. In this short period of time there is only a limited influence of temperature and ambient pressure. A stabilisation period of 10 minutes was used between changes of medium. Each measurement was carried out at least in triplicate. The leakage flow rates were calculated on the basis of absolute pressures.

[4] Based on the physical properties of nitrogen and air, it can be assumed that the nitrogen leak is the same as that with air, see also §4.5.

4. Results of theoretical consideration of leakage criteria

4.1 Flow rate ratios

The leak rate (the flow rate φ) of a given leak is determined not only by the shape and dimensions of that leak, but also by the (gaseous) medium flowing through the leak and by the pressure. These factors combined give a particular flow characteristic (laminar, turbulent or transitional) and ultimately result in a specific leakage flow rate. Applicable mediums that are used in the leak tightness tests are air or nitrogen, as well as the gas that will ultimately be distributed: natural gas or hydrogen. For the comparison between flow rates of these different substances flowing through the same leak, we can define different ratios (flow rate ratios), with no difference between nitrogen and air. This gives the following flow rate ratios:

$\varphi_{natural\ gas} / \varphi_{nitrogen}$

$\varphi_{hydrogen} / \varphi_{natural\ gas}$

$\varphi_{hydrogen} / \varphi_{nitrogen}$

As an example, the hydrogen to natural gas ratio varies between 1.3 and 3, depending on the flow characteristic (laminar, transitional or turbulent).

4.2 Principles for risk determination

The following principles have been chosen to determine the leak tightness requirements that should apply to hydrogen pipelines:

- Risks of a permissible hydrogen leak must be lower than or equal to the risks of a permissible natural gas leak
- Risks of leakage at service lines are high because they can lead to the gas escaping into a home or other building, with the risk of explosion
- The risk level for natural gas is based on a maximum permissible leak in accordance with NEN 7244-7
- If, as a result of a gas leak, the homogeneous concentration of a gas-air mixture in a room remains < 10% LEL, it can be assumed that no ignitable gas-air mixture (100% LEL) will be created inside that room
- The operating pressures are 30, 100 and 200 mbar
- The following aspects apply to determining the leak tightness requirement:
    - Risk of ignition of hydrogen versus natural gas for the same leak
    - Flow rate of hydrogen versus flow rate of natural gas for the same leak

4.3 Risk level in the event of a natural gas leak according to current regulations

The maximum leakage rate for the various components of a gas distribution pipe is stipulated in NEN 7244-7:2019 [1]. For connecting pipes, a distinction is made between new (max. 0.2 dm^3/h) and existing connecting pipes (max. 1 dm^3/h) when tested with air. The pressure test is carried out in compliance with VWI G-12 [2]. The requirement for new connecting pipes is more stringent than the requirement for existing pipes. A new pipeline may not leak unnecessarily as a result of installation errors or material faults. For an existing pipe, a minor but non-dangerous leakage that may have occurred due to ageing is considered allowable. The permissible leakage rate of 0.2 l/h is an acceptable limit for new connecting pipes, as it is derived from a permissible pressure drop of 1 mbar at varying measurement conditions. This requirement is no different for hydrogen than for natural

gas. Therefore, only the requirements for existing connecting pipes is relevant when looking into a revision of the requirements for hydrogen[5].

The requirements in [1] are partly based on a recommendation from the Expert Group on Interpretation of Small Gas Leaks. Calculations that form the basis for this recommendation are found in [3].

In addition to the flow rate of the gas released due to a leak, it is also important to make the comparison between the risks of natural gas and hydrogen. Both the probability of ignition and the consequences (fire or explosion) play a role in this comparison. [4] contains the following conclusion (*citation*):

Ignition
"The probability of air and hydrogen mixtures igniting at low concentrations of up to approximately 8 – 10 vol% is lower than natural gas"

Consequences: Fire or explosion
"*Fire will occur in an open space and at low concentrations <10 vol% of hydrogen in air). In the experiments found, no overpressures are observed at concentrations below 10% hydrogen. In closed spaces or at higher concentrations, there is a chance of explosions."*

Risk Comparison
"If a leak occurs inside a home or hydrogen enters the home by means of migration through the ground underneath the dwelling, the risk depends on the concentration that can be accumulated: If the concentration of hydrogen remains below 10 vol%, it poses a lower risk of harm or damage because the probability of ignition is lower than for natural gas, and because an explosion is unlikely to occur if ignited."

Based on the above findings, it can be assumed that at concentrations < 8% (conservative choice in the 8 – 10% mentioned above), the risks of ignition with hydrogen are lower than with natural gas at 5.9%[6] and that the consequences of ignition of a hydrogen-air mixture are less severe than when a natural gas-air mixture is ignited.

Limit situation for the comparison
Even though we state that a homogeneous gas concentration may not exceed 10% LEL value for natural gas in the event of leakage, 100% LEL of natural gas anywhere inside a room is the risk situation that must be avoided. This is regarded as the limit situation for making the comparison of hydrogen with natural gas.
Furthermore, the LEL values are based on the following:

- LEL value of Groningen natural gas = 5.9 vol% (see ref.[5]) in dry natural gas/air mixture
- LEL value of hydrogen = 4.0 vol% (see ref.[6] en [7]) in dry hydrogen/air mixture

4.4 Determination of tightness test criterion

To establish a leakage criterion for hydrogen, a factor $X_{tightn.\ tes.\ crit.}$ is determined in order to convert an existing leakage criterion for natural gas to a criterion for hydrogen. The basis for calculating this factor is a leakage rate at which the LEL value for natural gas is reached (5.9%). It is essential that the flow rate ratios are taken into account when establishing the conversion factor to hydrogen, for the

[5] For an overview of the requirements in the various regulations, see the Appendix III Overview criteria I.
[6] Reference [4] is based on the LEL value for methane, 5.3 vol%.

simple reason that the leak tightness tests are performed with air, as explained in section 4.1. The risk comparison is also taken into account as explained in section 4.3.

Based on the flow rate ratios, it can be deduced that if hydrogen is discharged at the same leak point and under the same conditions, a concentration of hydrogen is reached that is equal to:
[hydrogen] = [natural gas] x $\varphi_{hydrogen}$ / $\varphi_{natural\ gas}$ [vol%]
where the flow rate ratio $\varphi_{hydrogen}$ / $\varphi_{natural\ gas}$ follows on from the measurement results presented in the report below.

Based on §4.3, it can be assumed that 8 vol% hydrogen has a similar risk level as 5.9 vol% natural gas. This means that the permitted hydrogen leakage flow rate can be 8%/5.9%, or a factor of 1.36 greater than the permitted natural gas leakage flow rate.

For determining factor $X_{tightn.\ tes.\ crit.}$, both the flow rate ratios and the factor based on the risk comparison are used. This factor is calculated as follows:

$$X_{tightn.\ test.\ crit.} = \frac{1{,}36}{[\varphi_{hydrogen}\ /\ \varphi_{natural\ gas}\ ]}$$

Where [$\varphi_{hydrogen}$ / $\varphi_{natural\ gas}$] results from the measurement results; see next chapter.

Using this factor, a proposal for a tightness criterion for hydrogen can then be formulated based on table 4 from NEN 7244-7, and subsequently a proposal can be made for the modification to hydrogen from VWI G-12.

4.5 Flow properties in case of gas leaks

In leak tightness testing, only a small leak at most will be deemed acceptable. The following data and assumptions become apparent in the various sources:

- In [8], the assumption is that small hydrogen leaks have a laminar character with a $\varphi_{hydrogen}$ / $\varphi_{natural\ gas}$ flow rate ratio of 1.25
- It is asserted in [4] that:
  - Laminar flow: hydrogen leakage is a factor of 1.3x that of natural gas.
  - Turbulent flow: hydrogen leakage is a factor of 2.9x that of natural gas.
- In [9]: When testing with air in indoor pipes, the testing time that applies to natural gas for the same allowable pressure drop must be extended by a factor of 1.56. This factor is based on the differences in dynamic viscosity (μ), and thus assumes laminar leaks.
- In [10] it states that for small leaks in indoor installations, for example due to leaky threaded fittings, etc., laminar leaks occur for which a $\varphi_{hydrogen}$ / $\varphi_{natural\ gas}$ flow rate ratio of 1.2 applies (20% more H_2 in relation to CH_4). For boreholes, the basis is a turbulent flow with a flow rate ratio of 2.8. The leakage flow rate in boreholes is so great, however, that the connecting pipe for testing cannot be pressurized properly and will therefore not be approved under any circumstances.

Flow rate ratios in laminar and turbulent flow

The dynamic viscosity is the determining factor for the flow rate in a laminar flow. The determining factor for turbulent flow is the tightness. Table 1 contains the various physical data that are used as starting point[7].

[7] For an overview of viscosity data, see [11]. Also the density according to Table A11 from [5]. For the kinematic viscosity, the ρ is corrected to 20°C.

Table 1 Physical data of gases

Gas	Absolute viscosity (μ) [10^{-5} Pa.s]		Kinematic viscosity (v) at 20°C	ρ at 0°C and 1013 mbar
	Temperature [°C]			
	0	20	[$m^2/s \times 10^{-5}$]	kg/m^3
Air (dry)	1.73	1.82	1.506	1.2931
Nitrogen	1.66	1.76	1.527	1.2504
Methane	1.03	1.1	1.654	0.7175
Hydrogen	0.84	0.88	10.64	0.0898
Groningen gas		1.142[8]	1.47	0.833

The difference between the viscosity of air and nitrogen is only small, and therefore it can be expected that for small leaks the outflow will be virtually identical.
Where laminar flow is concerned, the following flow rates apply, assuming that the flow rate is inversely proportional to the viscosity (and assuming viscosity at 20 °C and natural gas = Groningen gas), giving:

$\phi_{natural\ gas}/\ \phi_{N2} =$ $\nu_{N2}\ /\ \nu_{natural\ gas} =$ 1.76/1.142 = 1.54
$\phi_{H2}/\ \phi_{natural\ gas} =$ $\nu_{natural\ gas}\ /\ \nu_{H2} =$ 1.142/0.88 = 1.3
$\phi_{H2}/\ \phi_{N2} =$ $\nu_{N2}\ /\ \nu_{H2} =$ 1.76/0.88 = 2.0

For a turbulent flow, the following proportionality applies:

$\Delta p \sim ½\ \rho.v^2$

with:
Δp = pressure difference that occurs
ρ = density of the gas
v = velocity of the gas

Based on the above, the following formula applies: $v_2/v_1 = \sqrt{(\rho_1/\ \rho_2)}$

To view the values for ρ, see the table under Ad 1). From these data and the above formula, we get the following:

$\phi_{natural\ gas}/\ \phi_{N2} = \sqrt{(\rho_{N2}/\ \rho_{natural\ gas})} =$ $\sqrt{(1.2504/0.833)} =$ 1.23
$\phi_{H2}/\ \phi_{natural\ gas} = \sqrt{(\rho_{natural\ gas}/\ \rho_{H2})} =$ $\sqrt{(0.833/0.0898)} =$ 3.0
$\phi_{H2}/\ \phi_{N2} =$ $\sqrt{(\rho_{N2}/\ \rho_{H2})} =$ $\sqrt{(1.2504/0.0898)} =$ 3.7

It should also be noted that, for a given leak, turbulent flow is less likely to occur with hydrogen than with natural gas because the Reynolds number for a given leak will be lower with hydrogen than with natural gas. The velocity for hydrogen is higher than for natural gas (depending on whether the flow is laminar or turbulent it is a factor of 1.25 - 3) but also the kinematic viscosity of hydrogen is higher than that of natural gas (factor of 6.4). For a given leak, the *Re* for hydrogen is therefore 0.2 - 0.5 of the *Re* for natural gas[9].

$$Re = \frac{\upsilon \cdot L \cdot \rho}{\mu} = \frac{\upsilon \cdot L}{\nu}$$

with
υ = velocity

[8] At 15°C, See page 80 [5]
[9] In [10] it states that the Re for hydrogen is smaller by a factor of 6.4 than for natural gas. But that only applies when the same velocity prevails.

L = characteristic length (with pipes this is the pipe diameter)
ρ = density
μ = dynamic viscosity
ν = kinematic viscosity (= μ/ρ)

NB. There is no significant difference in kinematic viscosity between air, nitrogen and natural gas, which means it is very likely that the nature of the flow (laminar or turbulent) in a given leak will be virtually equal for all gases. This does not apply to hydrogen. In certain leaks with hydrogen, a laminar flow or a transitional flow can occur; the nature of the flow in the same leak is turbulent when natural gas, nitrogen and air are used.

5. Measurement results

This section contains the results of the measurements that were performed. It concerns the average leakages as determined for each type of leak, the pressure and medium used. The full measurement results are included in Appendix VI Results of measurements leak-tightness

Two types of leaks were set up and are specified with A and B. The A leaks are the smallest leaks. The leak flow rate with nitrogen is 1 l/h at a pressure of 100 mbar. The B leaks are slightly larger because the leakage rate of 1 l/h of nitrogen is set at a pressure of 30 mbar. Furthermore, the leaks were made with different types of couplings, indicated by the numbers 1 to 4.

Table 2 gives a description of the leaks created. Further explanation and photographs of the constructions are provided in Appendix V. Table 3 contains an overview of the average values of the leakage flow rates, and also shows the ratios of the leakage flow rates for the different gases. Tables 4, 5 and 6 offer further break-downs of the data in Table 3.

Table 2 Description of types of leaks

Leak no.	**Leak set-up**	**Leak position**	**Measured pressures** (mbar)	**Leak creation method**
1A	≈ 1 l/h with nitrogen 100 mbar	PE steel coupling	30-100-200	welding thread between seal ring and PE pipe
1B	≈ 1 l/h with nitrogen 30 mbar	PE steel coupling	30	welding thread between sealing ring and PE pipe - looser coupling
2A	≈ 1 l/h with nitrogen 100 mbar	Coupling saddle tee piece / service line	30-100-200	wire between PVC and PE with scratches on PE
2B	≈ 1 l/h with nitrogen 30 mbar	Coupling saddle tee piece / service line	30-100	wire between PVC and PE and scratches on PE and 2 deep grooves
3A	≈ 1 l/h with nitrogen 100 mbar	sealing ring saddle / main pipe	30-100-200	single wire
3B	≈ 1 l/h with nitrogen 30 mbar	sealing ring saddle / main pipe	30-100	bundle of wires
4A	≈ 1 l/h with nitrogen 100 mbar	inlet valve connection on gas meter	30-100-200	thread between thread and coupling
4B	≈ 1 l/h with nitrogen 30 mbar	inlet valve connection on gas meter	30-100	wire around sealing ring

Note: eight different leaks were therefore measured, with variations in pressure and medium.

The results (see table 3) show that there is no clear variation in flow rate ratios for each type of coupling. Furthermore, the differences between the ratios measured at 100 and 200 mbar are only minor. As an example: the hydrogen/natural gas ratio at leak 1A is 1.56 at 100 mbar and 1.75 at 200 mbar.

Table 3 Average leakage rates for nitrogen, hydrogen and natural gas and the ratios between them

leak no.	pressure [mbar]	avg. ϕN2 [l/h]	avg. ϕ natural gas [l/h]	avg. ϕH2 [l/h]	ϕnatural gas / ϕN2	ϕH2/ ϕ natutral gas	ϕH2/ ϕN2
1A	30	0,29	0,44	0,46	1,51	1,05	1,59
	100	0,92	1,00	1,56	1,09	1,56	1,70
	200	1,39	1,59	2,78	1,14	1,75	2,00
1B	30	0,95	1,23	1,70	1,29	1,38	1,79
2A	30	0,25	0,53	0,53	2,12	1,00	2,12
	100	0,52	0,56	1,37	1,07	2,45	2,63
	200	0,92	1,26	2,36	1,37	1,87	2,56
2B	30	1,52	2,61	3,38	1,71	1,30	2,22
	100	3,93	5,89	10,01	1,50	1,70	2,55
3A	30	0,27	0,12	0,41	0,44	3,42	1,52
	100	0,54	0,70	1,43	1,30	2,04	2,65
	200	1,10	1,21	2,35	1,10	1,94	2,14
3B	30	1,04	1,61	2,40	1,55	1,49	2,31
	100	3,05	4,31	7,08	1,41	1,64	2,32
4A	30	0,37	0,37	0,52	1,00	1,41	1,41
	100	1,07	1,38	2,30	1,29	1,67	2,15
	200	1,81	2,28	3,92	1,26	1,72	2,17
4B	30	0,88	1,26	2,01	1,43	1,60	2,28
	100	2,12	3,03	5,52	1,43	1,82	2,60

Explanation with table 3.

A leakage rate of approximately 1 litre per hour was set for the A leaks with nitrogen pressure at 100 mbar. In addition to the measurements taken at 100 and 200 mbar, measurements were also taken at 30 mbar. As expected, the pressure drop at 30 mbar is significantly lower in relation to the pressure drops at 100 mbar. This means the measurements taken at 30 mbar are less accurate. The 30 mbar measurements at the A leaks have therefore been shaded dark grey in the table above. When determining and recording the ratios between leakage flow rates, the 30 mbar measurements of the A leaks were not included. The ratios between hydrogen and natural gas at the 100 mbar leaks 2A and 3A are somewhat on the high side (2.45 and 2.04) compared to the other ratios. As mentioned above, this may be caused by the reduced accuracy due to small pressure drops or low flow rates (0.52 and 0.54 l/h). Since leak rates of 3.93 and 3.05 l/h were measured in the 2B and 3B at the 100 mbar set-ups, it was decided to include the small leakages of 2A and 3A in the further determinations. Ultimately, one single factor is determined that is valid for all pressure levels (30, 100 and 200 mbar), the different types of leaks (four measured in this study) and different leakage rates (in this case 0.5 to 4 l/h based on nitrogen). For this reason the 100 mbar leaks 2A and 3A are included in the further determinations.

In leak no. 1, the leakage flow rate of 1 l/h was reached (setting N_2) at 30, 100 and 200 mbar for the four measurements taken. For the other A leaks (especially 2 and 3), the flow rate at 100 mbar was somewhat on the low side. For this reason, the 100 mbar measurements were taken at the other B leaks. N.B. Setting a variation of leakages of approximately 1l/h is difficult in practice (reduce leak opening slightly and it is tight).

The table below shows the ratios between the leakage flow rates of hydrogen and natural gas. An average ratio is also included, based on the 3 or 4 leakages measured. At 100 and 200 mbar,the average ratio rises towards the value of 2.

Table 4 Leakage flow rate ratios for hydrogen/natural gas per leak and per pressure

Description of leakage setting	pressure [mbar]	leak 1	leak 2	leak 3	leak 4	average
A leak (≈ 1 l / h 100 mbar N_2)	100	1.56	2.45	2.04	1.67	1.93
	200	1.75	1.87	1.94	1.72	1.82
B leak (≈ 1 l / h 30 mbar N_2)	30	1.38	1.30	1.49	1.60	1.44
	100	-	1.70	1.64	1.82	1.72
The average ratio of the A and B leaks at 100 mbar is 1.84						

Table 5 gives the average flow rate ratios of all measured gases, whereby less accurate measurements (type A leaks at 30 mbar) have been omitted. For a more detailed consideration, see Chapter 6.

Table 5 Average ratios per pressure level based on leakages excluding type A leaks at 30 mbar.

pressure [mbar]	ϕnatural gas/ ϕN2	ϕH2/ ϕnatural gas	ϕH2/ ϕN2
30	1.49	1.44	2.15
100	1.30	1.84	2.37
200	1.22	1.82	2.22
Total of all measurements (no distinction regarding pressure)	1.33	1.73	2.27

6. Consideration of results

6.1 Determination of the factor for leak tightness testing

The values of the flow rate ratios from table 5 are used as the starting point for the further consideration.

For each pressure level, a comparison has been made of the calculated flow rate ratios for laminar and turbulent flow with the average values of the flow rate ratios based on the measurement results. Using this comparison as the basis, the last column indicates the probable flow character of the leaks for each of the measurements.

Table 6 Average values of flow rate ratios in the measurement results and calculated values for laminar and turbulent flow and characterisation of the flow

Flow rate ratio	Calculated flow rate ratio (Chapter 4)		pressure [mbar]	Measured flow rate ratio (Chapter 5)	Flow character of measured leaks (based on comparison with calculated flow rate ratios)
	lam.	turb.			
$\varphi_{natural\ gas}/\varphi_{N2}$	1.54	1.23	30	1.49	natural gas and nitrogen laminar
			100	1.30	natural gas and nitrogen turbulent
			200	1.22	
			avg.	**1.33**	n/a (because of average of flow characteristics at the different pressure levels)
$\varphi_{H2}/\varphi_{natural\ gas}$	1.3	3.0	30	1.44	natural gas and hydrogen laminar
			100	1.84	Natural gas is turbulent (see $\phi_{natural\ gas}/\phi_{N2}$) *) So hydrogen is laminar or in transition range.
			200	1.82	
			avg.	**1.73**	n/a Avg. value approaches result in[12] ≈1.6. However, no significant difference was found in the leakage ratio at 25 and 100 mbar in[12].
ϕ_{H2}/ϕ_{N2}	2.0	3.7	30	2.15	hydrogen and nitrogen laminar
			100	2.37	Nitrogen turbulent (see $\phi_{natural\ gas}/\phi_{N2}$) Hydrogen is therefore either laminar or in transition range.
			200	2.22	
			avg.	**2.27**	n/a

*) Note: The flow rate ratio indicates that the leakage flow at 30 mbar is laminar for both natural gas and hydrogen. Natural gas leakage flow at 100 and 200 mbar is more turbulent (see row $\phi_{natural\ gas}/\phi_{N2}$, where these flow rate ratios at 100 and 200 mbar are 1.30 en 1.22 respectively. These values approach the theoretical ratio of 1.23 for turbulent flow). If the flow of hydrogen at 100 and 200 mbar were also turbulent, the flow ratio $\phi_{H2}/\phi_{natural\ gas}$ should be nearer 3.0. This is not the case and the conclusion is therefore that the flow of hydrogen is either laminar or in the transition range between laminar and turbulent.

Considerations based on these measurement results:

- A factor of 1.64 is mentioned in ref [12]. This is a value based on flow rate measurements with pressures of 25 and 100 mbar at two different leakages. This concerned a leakage through a screw thread and a leakage through a compression coupling.

Four different types of leaks were examined in this study. Three of the four leaks involved a leak between a rigid material (pipe) and a sealing ring. These three leaks may respond dynamically to some extent, depending on pressure and medium. The fourth leak involved a leak on a threaded connection and, in that respect, is similar to one of the two tested leaks described in ref [12]. The average value for the hydrogen/natural gas ratio for the fourth leak is 1.70.

- The measurements of various field leaks show a difference in flow characteristics between leaks at 30 mbar on the one hand and at 100 and 200 mbar on the other. In the VIAG VWI G-12, a test pressure of 200 mbar is used for connecting pipes with an operating pressure of 100 mbar. In daily practice (in the event of faults or other work), the operating pressure is generally used to carry out leak tightness tests. The flow rate ratio ϕ_{H2}/ $\phi_{natural\ gas}$ of the average measurement values at 100 and 200 mbar are 1.82 and 1.84 respectively. On average we assume a flow rate ratio ϕ_{H2}/ $\phi_{natural\ gas}$ of 1.83.
- For a given leak where the same risk should apply for hydrogen as for natural gas, the following multiplication factor should be applied in the leak tightness test at 100, 200 or 300 mbar to determine the permissible leakage with air:

$$X_{criterium\ dichtheidsbeproeving} = \frac{8\ [\%]}{5{,}9[\%] \cdot 1{,}83[=\ \varphi_{waterstof}\ /\ \varphi_{aardgas}\ ]} = 0{,}74$$

- Existing pipes of 30 mbar are tested at 40 mbar (VWI G12). A flow rate ratio φ_{H2}/ $\varphi_{natural\ gas}$ of approx. 1.44 can apply at this lower pressure. The multiplication factor in this case would give the value $X_{leak\ tightness\ test\ criterion}$ = 0.94. This would result in a less stringent tightness requirement than for a 100 mbar pipe network. There are two reasons, however, why it is distinguishing between 30 mbar and 100 mbar pipes is not recommended:
    - In practice, it can possibly be difficult to explain to the technician that the tightness requirement is less stringent at lower pressures.
    - A 30 mbar pipe can also be set-up as a 100 mbar pipe in the future, which leads to the reasonable advice of adhering to the tightness requirements for a 100 mbar pipe.
- If no distinction is made in the pressure level, an average flow rate ratio ϕ_{H2}/ $\phi_{natural\ gas}$ of 1.73 applies. This is close to the earlier findings of Kiwa in[12], where no distinction was found between 25, 100 and 200 mbar leaks. If a factor of 1.73 were to be assumed, a factor $X_{leak\ tightness\ test\ criterion}$ = 0.78 applies. However, this factor incorrectly softens the criterion for leaks at pressures of 100 and 200 mbar.
- Taking the previous points into consideration, it is recommended to use the average flow rates at 100 and 200 mbar for the leak tightness test of connecting pipes. This leads to a multiplication factor of 0.74 for the leak tightness requirement in the regulations.
- The following applies to mains pipes. Assuming a worst case with a turbulent leak, a leakage size of 5 l/h of nitrogen or air corresponds to a natural gas leakage of approximately 6.2 l/h and a maximum hydrogen leakage of 18.5 l/h. (For a laminar leak, a natural gas flow rate of 7.7 l/h and a hydrogen flow rate of 10 l/h corresponds to a leak rate of 5 l/h air). Such small leaks are acceptable for main pipelines because they do not result in dangerous concentrations of hydrogen.
  Moreover, when converting an existing natural gas network to a hydrogen network, it will not be easy to test the main pipeline for leakage using a pressure drop test. This means the exact leakage flow rate will be difficult to determine. During the conversion, the leak tightness of the main pipelines will have to be assessed by means of an above-ground leakage search. This leakage search should preferably be carried out shortly before the

conversion (detection of natural gas), so that unforeseen leaks can be repaired before a conversion. A leak search round can subsequently be done after the conversion (detection of hydrogen) with periodic leak search rounds thereafter in accordance with NEN 7244.
An existing natural gas network was originally constructed on the basis of a leak tightness requirement of 5 l/h (criterion as of 2005 described in NEN 7244-7). In other words, this has an acceptable leak tightness level from the outset. Leak tightness is monitored by means of periodic leakage searches.

6.2 Proposal for changes to the tightness requirement for hydrogen

Based on the above considerations, the proposal for the tightness requirement is as follows:

For a given leak where the maximum risk for hydrogen and natural gas must be the same, a multiplication factor of 0.74 must be applied in the tightness test for the permissible leak with air or nitrogen.

Based on the current requirements, the requirements for hydrogen as shown in table 7 should then apply:

Table 7 NEN 7244-7, table 4, maximum leak rate: (test with air or nitrogen) with modification for hydrogen

Maximum leak size at a test pressure equal to MOP		
Type of pipe	**Natural gas Max. leak rate [air or N_2 dm^3/h]**	**Hydrogen Max. leak rate [air or N_2 dm^3/h]**
Main pipeline	5.0	5.0
Service pipeline - new*)	0.2	0.2
Service pipeline - existing**)	1.0	0.7
Meter set-up*)	0.1	0.1

*) A new pipeline may not leak unnecessarily as a result of installation errors or material faults. The maximum leakage rate of 0.2 l/h is feasible in practice and is therefore regarded as desirable for new connecting pipes. (Feasible in practice based on small allowable leaks from new components and varying measurement conditions). This requirement is the same for natural gas and hydrogen. The same requirement also applies to the meter set-up.
**) A connecting pipe is considered existing as soon as the report of the first leak tightness test of the new pipe is accepted by the network operator.

VWI G-12 can possibly incorporate the following supplement for hydrogen (text is taken from the current VWI G-12, **proposed *addition in bold and italics***):

- A new connecting line is considered leak tight if the test pressure drops ≤ 1 mbar during an overpressure measurement (at a constant temperature). If the pressure increase is ≤ 1 mbar, the pipe can be considered gas tight. If the pressure increase is > 1 mbar, the pressure test must be carried out again.
- An existing connecting pipe is considered leak tight if the test pressure drops ≤ 5 mbar during an overpressure measurement (at a constant temperature) (***for hydrogen pipes: ≤ 4 mbar***).[10]

[10] N.B. No distinction was deliberately made between test requirements for 30 mbar or 100/200 mbar pipelines for the sake of simplicity, as it may be difficult to explain to technicians that a milder criterion would apply to 30 mbar pipelines on the basis of the flow characteristics than to 100 and 200 mbar pipelines.

Again, if the pressure increase ≤ 1 mbar, the pipe can be considered leak tight. If the pressure increase is > 1 mbar, the pressure test must be carried out again.

- A connecting pipe is considered existing as soon as the report of the first leak tightness test (overpressure measurement) of the new pipe is accepted by the network operator.

Given the adjustment of the pressure drop criterion from a maximum of 5 mbar to a maximum of 4 mbar, VWI G12, table 3 can remain unchanged.

N.B. The VWI G-12 also refers to a calculation tool from Kiwa, which can be downloaded:
https://www.kiwa.com/nl/nl/over-kiwa/specialistische-services/kiwa-technology/downloads/
The permissible leak rates in this calculation tool should also be adjusted in accordance with the amendments in standard 7244-7.

7. Conclusions, answer to research question and advice

7.1 Conclusions and answer to research question

Leak tightness requirements

For new service pipes, the same leak-tightness requirements can be used for hydrogen and for natural gas. There is no reason to make the criteria more stringent.

For existing connecting pipes, the tightness requirements must be made more stringent. The maximum permissible leakage rate for existing hydrogen service pipelines is 74% of that for natural gas. This has been determined on the basis of the following:

- The measured values give a factor of 1.83 higher leakage for hydrogen
- The assumption 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%

These tightness requirements can be incorporated by extending NEN 7244-7, table 4 for hydrogen, which would then read as follows

Maximum leak size at a test pressure equal to MOP		
Type of pipe	**Natural gas Max. leak rate [dm^3/h]**	**Hydrogen Max. leak rate [dm^3/h]**
Main pipeline	5.0	5.0
Service pipeline - new*)	0.2	0.2
Service pipeline - existing**)	1.0	0.7
Meter set-up	0.1	0.1

The strength tests and leak tightness tests for a hydrogen network can be updated by adding the following sentence in VWI G-12 (*in italics*):

An existing connecting pipe is considered leak tight if the test pressure drops ≤ 5 mbar during an overpressure measurement (at a constant temperature) (*for hydrogen pipes: ≤ 4 mbar*)

Laminar and turbulent flows at different pressures

The measured values with nitrogen, natural gas and hydrogen show the following. For a given leak, the following applies to the relationship between the flow rate of hydrogen and that of natural gas (the flow rate ratio):

- The flow rate ratio is 1.44 for pressure tests at 30 mbar, which indicates that the leakage flow is laminar for natural gas, hydrogen and nitrogen.
- For pressure tests at 100 and 200 mbar, this flow rate ratio is 1.83 on average. The flow of natural gas and nitrogen is turbulent and the flow of hydrogen is laminar or in the transition area.

7.2 Advice

The following is recommended when converting from natural gas to hydrogen:

- perform leak tightness test on every connecting pipe by means of a pressure drop test
- main pipelines should be tested for leak tightness by means of an above-ground leak search

A limit value of 10 ppm is currently still used for leak searches with hydrogen. Ref [13] indicates that this criterion requires further investigation.

References

[1] NEN 7244-7:2019
[2] VWI G-12: LD-aansluitleidingen veilig beproeven op sterkte en dichtheid versie 15-04-2021
[3] Voorstel aanpassing lekdichtheidscriteria voor NEN normcommissie NEN 7244, dd 22 november 2013, inclusief bijlagen.
[4] Gedrag van waterstof bij lekkages in het gasdistributienet -DNVGL 184991
[5] Basisgegevens aardgassen – 1980 Nederlandse Gasunie
[6] Hy4Heat Work package 7 Safety Assessment: Gas Ignition and Explosion Data Analysis
[7] USBM-503 Limits of Flammability of gases and vapors - Coward and Jones
[8] Toekomstbestendige gasdistributienetten – Kiwa GT-170272
[9] NPR 3378-2: 2013: tabel A.1
[10] Hy4Heat Work package 7 Safety Assessment: Experimental Testing - Domestic Pipework Leakage
[11] https://www.engineeringtoolbox.com/gases-absolute-dynamic-viscosity-d_1888.html
[12] Eerste inventarisatie naar waterstofuitstromen bij kleine toelaatbare lekken – Kiwa GT-180259
[13] De verspreiding van aardgas en waterstof in de bodem – Kiwa GT-200302

I List of questions HyDelta WP1C

The following questions are addressed in this work package.

- Question number HyDelta 187: Research into the safe commissioning and decommissioning of pipeline sections in hydrogen distribution during the conversion to a hydrogen network and the associated costs.
- Question number HyDelta 124: Research into the performance of strength and density tests.
- Question number HyDelta 135: What is the effect of the existing gas network on the quality of hydrogen in distribution and transport?
- Question number HyDelta 185: Home pressure regulator: What are the risks if it is not modified?
- Question number HyDelta 101: Investigation of risks related to existing gas installations (at the customers) when converting from natural gas to 100% hydrogen.
- Question number HyDelta 61: How is it ensured that the developments of all components suitable for 100% hydrogen are integrated - in the distribution network (incl. connections), in the indoor installation and in the gas consumption appliances in homes and businesses - so that the entire chain is compatible?
- Question number HyDelta 55: What will a conversion to a hydrogen network look like

II List of participants Expert Assessment Group (EAG) question 124

Composition Expert- and Assessment Group (EAG)

Name	Employer
D. Nieuwenhuizen	Stedin
H. Smit	Enexis
W. Koppenol	Enexis
W.R. Nispeling	Alliander
R. den Hartog	Westland Infra
J. Jonkman	Rendo
R. Scholten	Rendo
A. Kooiman	Kiwa Technology
S. Lueb	Kiwa Technology

The EAG acts like a guidance and sparring group during this research.

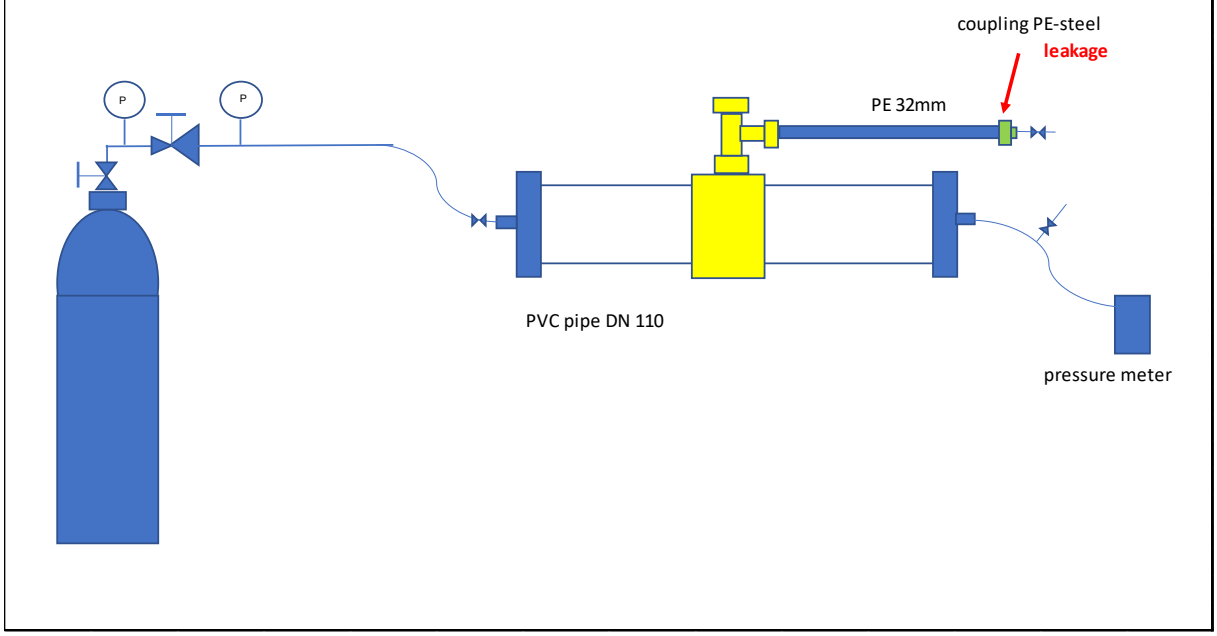
III Overview criteria leak tightness

<table>
<tr><th>Document</th><th>Lekdichtheidscriteria</th></tr>
<tr><td rowspan="2">NEN 7244-7: 2019</td><td>Leaktightness measurement with air for natural gas pipelines.</td></tr>
<tr><td>Testpressure: MOP or higher
<table>
<tr><th>Type pipe</th><th>Measurement with air
Max. leak rate [dm^3/h]</th></tr>
<tr><td>Main pipeline</td><td>5,0</td></tr>
<tr><td>Service pipeline – new</td><td>0,2</td></tr>
<tr><td>Service pipeline – existing</td><td>1,0</td></tr>
<tr><td>Meter set-up</td><td>0,1</td></tr>
</table></td></tr>
<tr><td rowspan="2">VIAG VWI G-12: 2021</td><td>Tightness measurement LD service lines</td></tr>
<tr><td>Testpressure: 200/300 mbar for pipes 100/200mbar
Testpressure 40 mbar for pipes 30 mbar
Pressure drop new: < 1 mbar in 5 minutes for new pipes < 13,1 dm^3
Pressure drop existing: < 5 mbar in 5 minutes for new pipes < 13,1 dm^3</td></tr>
<tr><td rowspan="2">KE 214</td><td>Tightness measurement with air for hydrogen components</td></tr>
<tr><td>External leak valves ≤50 DN: 6,6 cm^3/h. Testpressure 6 mbar and 1,5 x MOP
Extern leak regulators: 6,6 cm^3/h. Testpressure 300 mbar</td></tr>
<tr><td rowspan="2">KE 69-1</td><td>Leaktightness criteria for valves (natural gas). Testing with air.</td></tr>
<tr><td>External leak valves ≤50 DN: 20 cm^3/h. Testpressure 6 mbar and 1,5 x MOP</td></tr>
<tr><td rowspan="2">NEN 7239:2018</td><td>Leaktightness criteria for regulators (natural gas) Testing with air.</td></tr>
<tr><td>External leak regulators: 10 cm^3/h. Testpressure 300 mbar</td></tr>
<tr><td rowspan="2">NEN 1078:2018</td><td>Leaktightness criteria new gasinstallations natural gas < 500 mbar</td></tr>
<tr><td>Long term tight. No pressure drop allowed, in closed piping. Testpressure air 100mbar + nom. workingpressure. No pressure drop in 3 min.</td></tr>
<tr><td rowspan="2">NEN 8078+A1: 2018</td><td>Leaktightness criteria existing gasinstallations < 500 mbar ≤ 50 dm^3</td></tr>
<tr><td>< 5 dm^3/h natural gas</td></tr>
<tr><td rowspan="2">NPR 3378-1:2020</td><td>Determination leaktightness gasinstallations, guidance for NEN 1078 and NEN 8078</td></tr>
<tr><td>New: max 1 l/h natural gas. At volume < 50 l and testpressure 25 or 100 mbar:
Max. pressure drop with natural gas: 1 mbar in 3 min
Max. pressure drop with air or nitrogen: 1 mbar in 5 min
NB. Conversion factor = 5 min/3 min = 1,67.
Existing: < 5 dm^3/h natural gas. At volume < 50 l and testpressure 25 or 100 mbar:
Max. pressure drop met aardgas: 5 mbar in 3 min
Max. pressure drop met lucht of stikstof: 5 mbar in 5 min
NB Conversion factor = 5 min / 3 min = 1,67.</td></tr>
<tr><td rowspan="2">~~NPR 3378-2:2013 Vervallen~~</td><td>~~Aanvullende methoden bepaling dichtheid gasinstallatie < 50 liter~~</td></tr>
<tr><td>~~Correctiefactor voor beproeving met lucht: 1,56 x beproevingstijd met aardgas~~</td></tr>
</table>

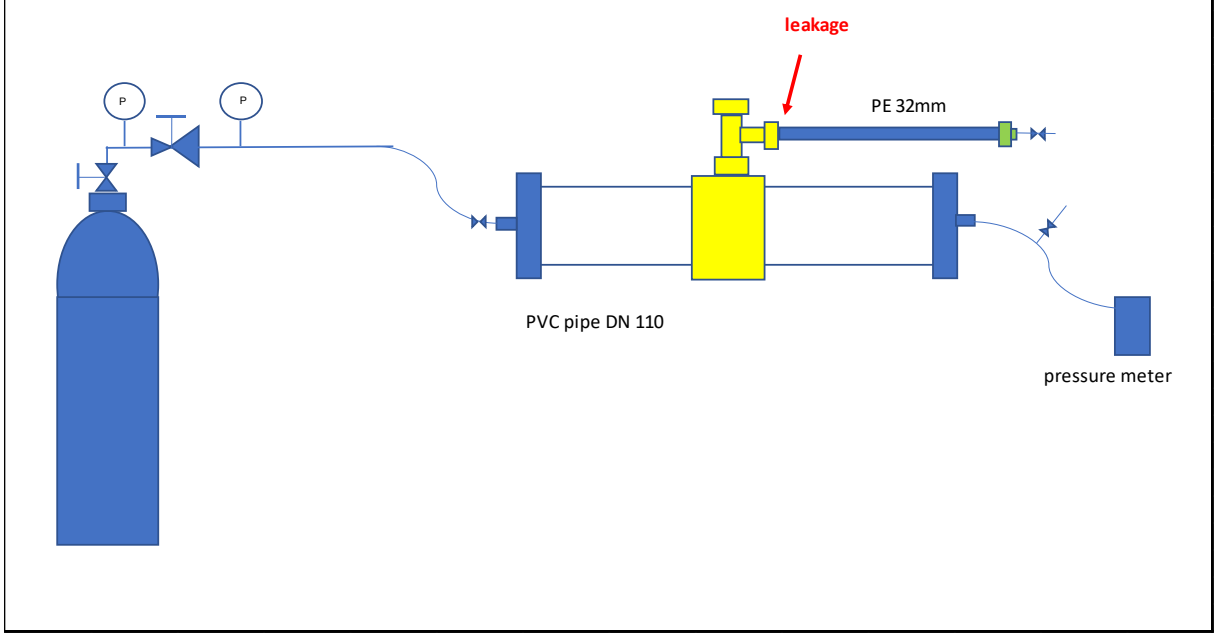
IV Detailed drawings of the test set-ups

Below is a schematic representation of the leakages from four different types of couplings. In the four set-ups, a leak of approximately 1 litre per hour of nitrogen is created at a pressure of 100 mbar and another leak at a pressure of 30 mbar. In total, eight different leak openings were measured.

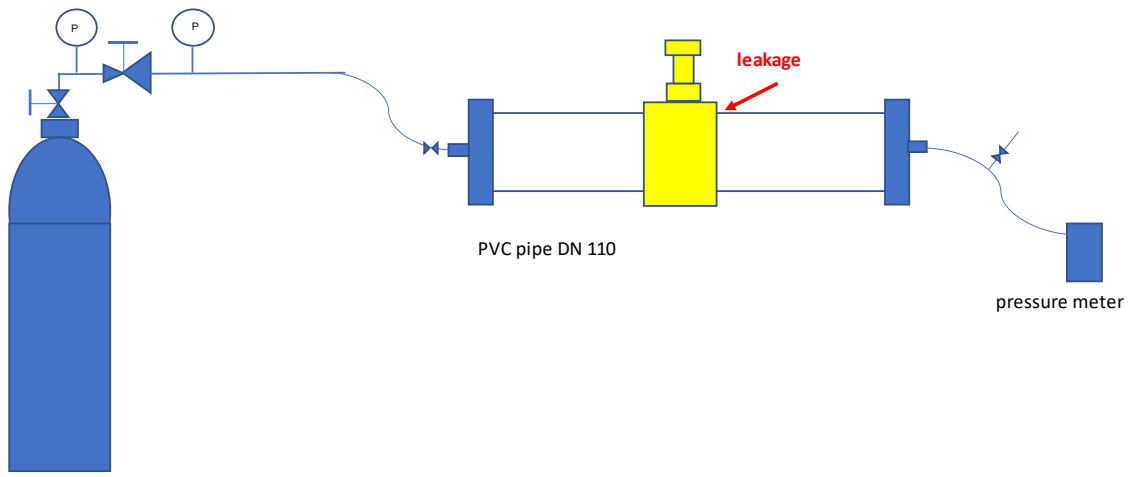
1) leakage on transition coupling PE-steel



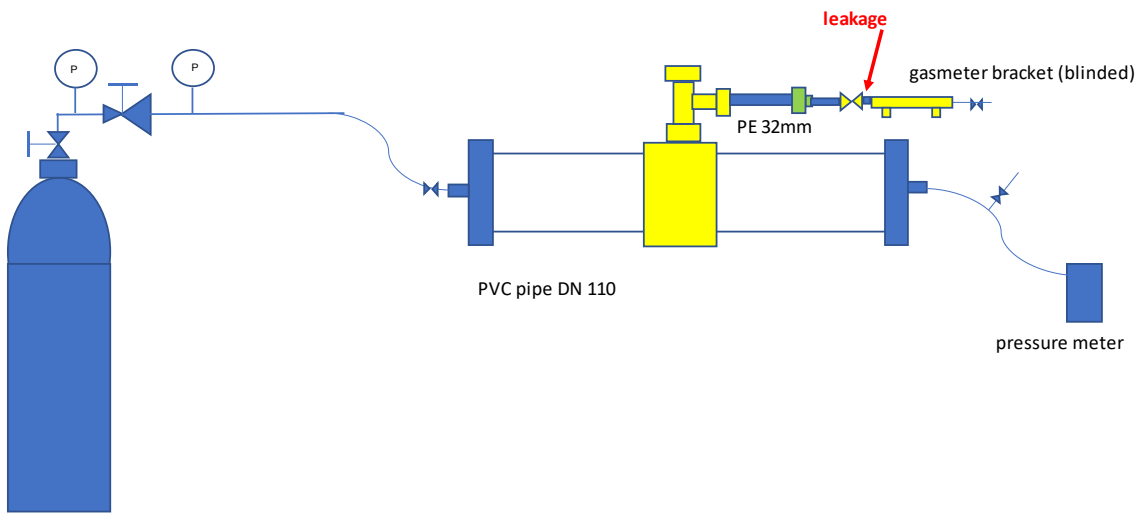
2) leakage on clamp-screw coupling of tee piece service line



3) leakage on sealing ring between saddle and main pipe

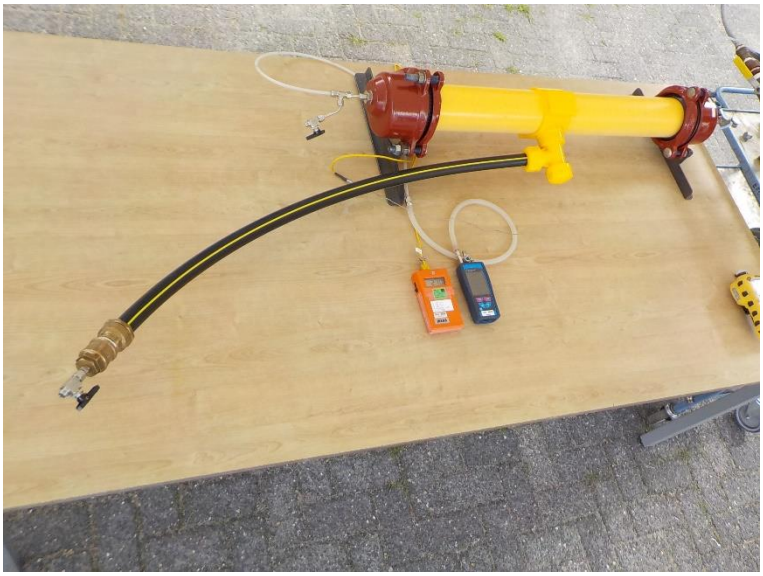


4) leakage on coupling of inlet valve at gasmeter



V Method of applying leaks

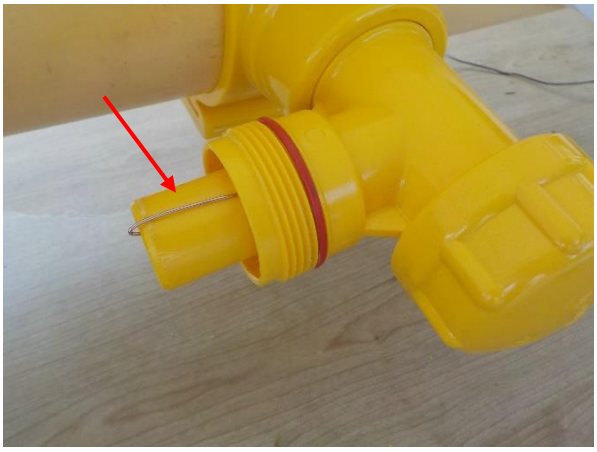
Overview of test set-up leak 1 and leak 2



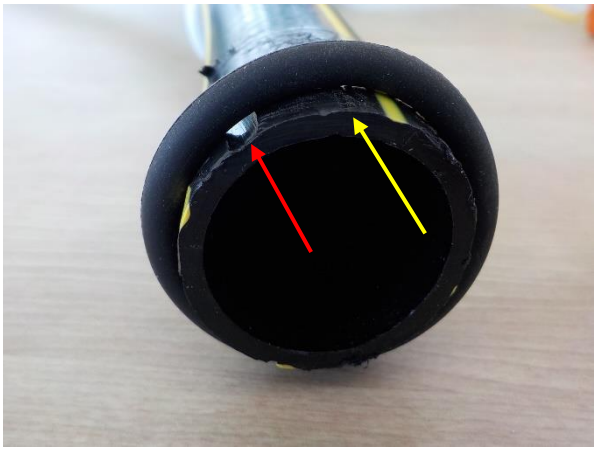
Leak 1: Steel PE transition coupling

Transition coupling of steel PE with valve for flushing. The leak is created by inserting a welding wire (0.8 mm^2) between the sealing rings and the PE pipe. At a setting of 100 mbar, the thread is turned tighter compared to the 30 mbar set-up.

Leak 2:



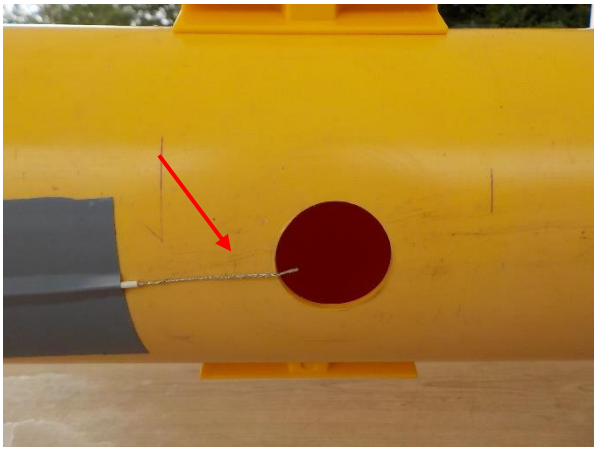
The leak is created by inserting welding wire (0.8 mm^2) between the support sleeve and the PE pipe (red arrows)

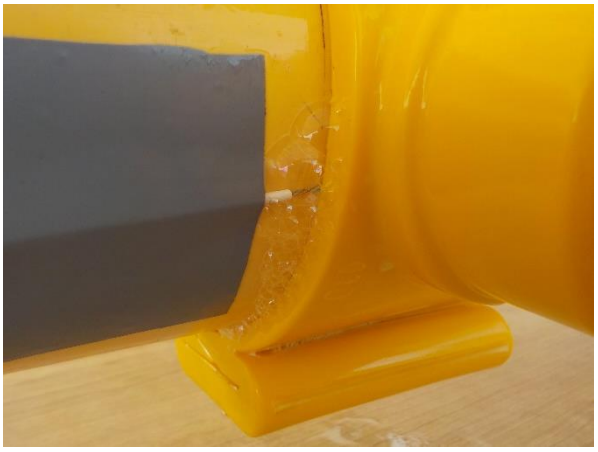


Scratches are made on the PE pipe (yellow arrow) with the set-up at 100 mbar and additional deeper grooves (red arrow) with the leak set-up at 30 mbar.

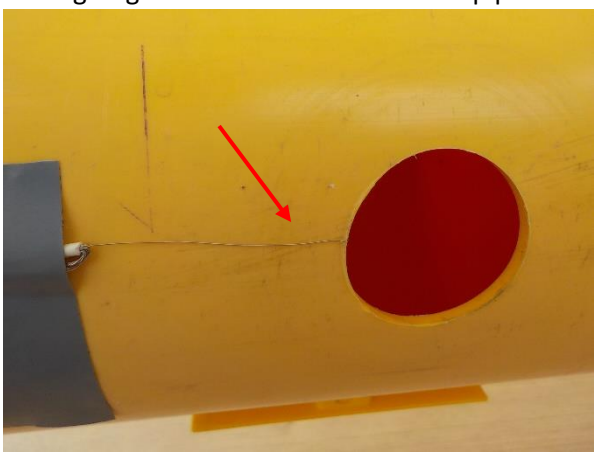
Overview of leak 3 test set-up

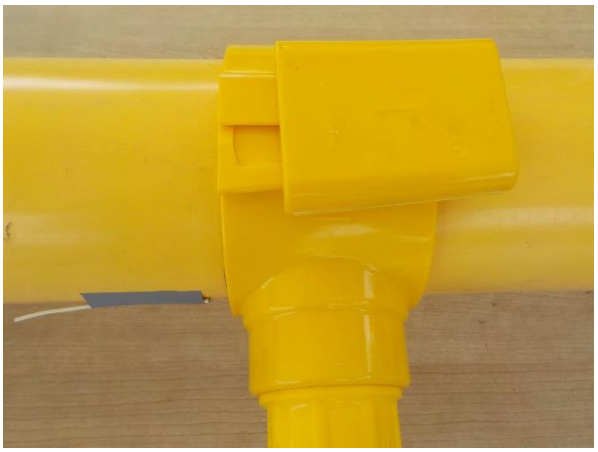
Leak 3:





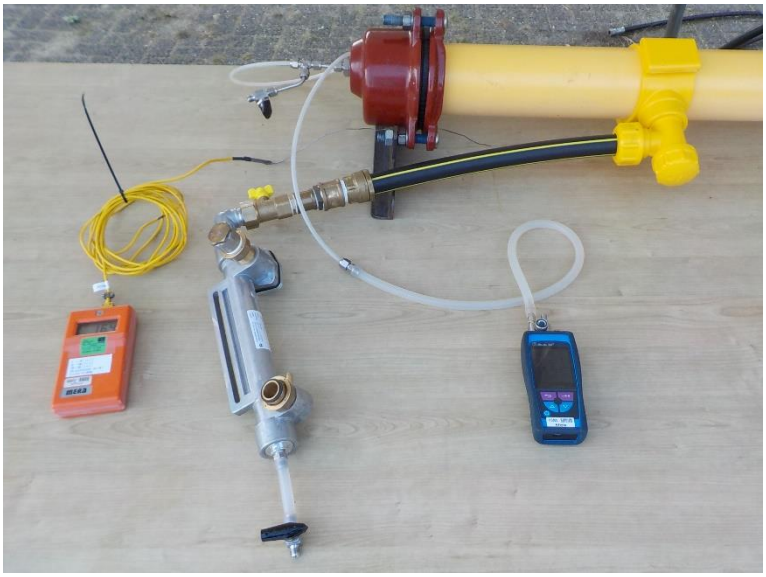
The leak at 30 mbar is created by placing electrical wire (bundle of wires, 0.5 mm^2) between the sealing ring of the saddle and the main pipe.



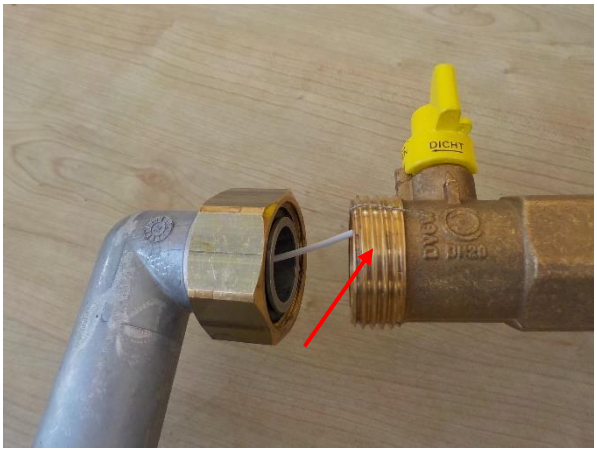


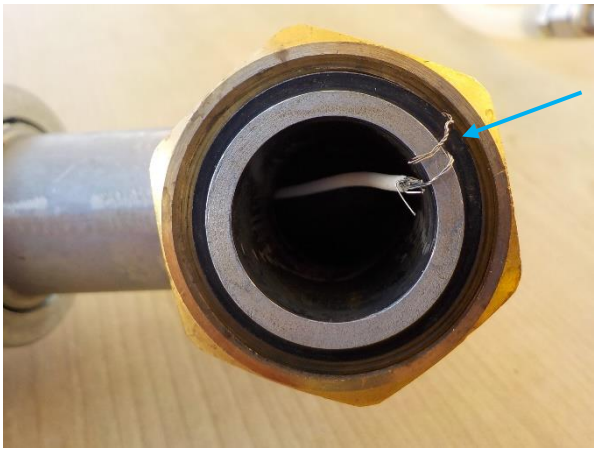
The leak at 100 mbar is created by placing a single electrical wire (0.02 mm^2) between the sealing ring of the saddle and the main pipe, and not closing the wedge completely.

Overview of leak 4 test set-up



Leak 4:





The leakage at 100 mbar is created by placing the electrical wire (0.5 mm2) between the thread and the nut (red arrow). The leakage at 30 mbar is created by placing electrical wire around the sealing ring (blue arrow).

VI Results of measurements leak-tightness

In this appendix an overview of all individual measurements. These are in the Dutch language, as a guidance see the first table below.

Dutch	English	Note
Lek	Leakage	
Omschrijving lek	Description leakage	See table 2 in chapter 5 for the description of leakages
Instelling nominale druk	Setting of nominal pressure	
P eind	P end	
Daling	Pressure drop	
Tijdsduur	Duration	
Debiet	Flow	
Stikstof	Nitrogen	
Waterstof	Hydrogen	
Aardgas	Natural gas	
Gemiddelde van alle waarden	Average of all values	

Lek 1A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 1 - koppeling PE-Staal	100	105,6	103,5	2,1	64,2	0,94
2	stikstof	nr 1 - koppeling PE-Staal	100	105,2	103,2	2,0	62,4	0,92
3	stikstof	nr 1 - koppeling PE-Staal	100	103,4	101,7	1,7	61,7	0,79
4	stikstof	nr 1 - koppeling PE-Staal	100	105,5	103,3	2,2	61,4	1,03
5	stikstof	nr 1 - koppeling PE-Staal	200	199,0	196,2	2,8	60,2	1,23
6	stikstof	nr 1 - koppeling PE-Staal	200	198,6	195,2	3,4	62,9	1,43
7	stikstof	nr 1 - koppeling PE-Staal	200	199,5	195,8	3,7	63,5	1,54
8	stikstof	nr 1 - koppeling PE-Staal	200	198,3	195	3,3	63,9	1,37
9	stikstof	nr 1 - koppeling PE-Staal	30	32,26	31,74	0,52	61,5	0,26
10	stikstof	nr 1 - koppeling PE-Staal	30	32,03	31,43	0,60	64,4	0,29
11	stikstof	nr 1 - koppeling PE-Staal	30	32,23	31,56	0,67	62,5	0,33

Druk	Medium	Gemiddeld lek	
30	stikstof	0,29	gemiddelde van alle waarden
100	stikstof	0,92	gemiddelde van alle waarden
200	stikstof	1,39	gemiddelde van alle waarden

Lek 1A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr 1 - koppeling PE-Staal	100	100,5	98,4	2,1	65,5	0,94
2	aardgas	nr 1 - koppeling PE-Staal	100	101,1	99,1	2,0	62,1	0,93
3	aardgas	nr 1 - koppeling PE-Staal	100	101,3	99,1	2,2	62,2	1,03
4	aardgas	nr 1 - koppeling PE-Staal	100	101,5	99,2	2,3	63,2	1,06
5	aardgas	nr 1 - koppeling PE-Staal	100	101,3	99,2	2,1	61,3	0,98
6	aardgas	nr 1 - koppeling PE-Staal	200	191,9	188,8	3,1	62,7	1,32
7	aardgas	nr 1 - koppeling PE-Staal	200	193,0	189,4	3,6	64,0	1,50
8	aardgas	nr 1 - koppeling PE-Staal	200	192,2	188,5	3,7	63,0	1,56
9	aardgas	nr 1 - koppeling PE-Staal	200	192,5	188,6	3,9	62,5	1,66
10	aardgas	nr 1 - koppeling PE-Staal	200	192,1	188,2	3,9	63,6	1,63
11	aardgas	nr 1 - koppeling PE-Staal	30	31,49	30,69	0,80	64,5	0,38
12	aardgas	nr 1 - koppeling PE-Staal	30	31,51	30,62	0,89	62,4	0,44
13	aardgas	nr 1 - koppeling PE-Staal	30	31,49	30,57	0,92	61,4	0,46
14	aardgas	nr 1 - koppeling PE-Staal	30	31,59	30,63	0,96	61,0	0,48

Druk	Medium	Gemiddeld lek	
30	aardgas	0,44	gemiddelde van alle waarden
100	aardgas	1,00	gemiddelde van alle waarden
200	aardgas	1,59	gemiddelde van alle waarden

Lek 1A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr 1 - koppeling PE-Staal	100	101,4	97,8	3,6	64,6	1,60
2	waterstof	nr 1 - koppeling PE-Staal	100	101,3	97,8	3,5	64,7	1,55
3	waterstof	nr 1 - koppeling PE-Staal	100	101,2	97,9	3,3	61,4	1,53
4	waterstof	nr 1 - koppeling PE-Staal	100	101,0	97,6	3,4	62,4	1,56
6	waterstof	nr 1 - koppeling PE-Staal	200	193,6	187,1	6,5	62,4	2,77
7	waterstof	nr 1 - koppeling PE-Staal	200	193,1	186,6	6,5	61,4	2,82
8	waterstof	nr 1 - koppeling PE-Staal	200	193,0	186,6	6,4	62,1	2,75
9	waterstof	nr 1 - koppeling PE-Staal	200	193,1	186,7	6,4	61,4	2,78
10	waterstof	nr 1 - koppeling PE-Staal	200	31,90	31,05	0,85	62,1	0,42
11	waterstof	nr 1 - koppeling PE-Staal	30	32,26	31,37	0,89	63,1	0,43
12	waterstof	nr 1 - koppeling PE-Staal	30	32,19	31,11	1,08	64,4	0,51
13	waterstof	nr 1 - koppeling PE-Staal	30	32,13	31,16	0,97	62,0	0,48
14	waterstof	nr 1 - koppeling PE-Staal	30	32,13	31,19	0,94	61,2	0,47

Druk	Medium	Gemiddeld lek	
30	waterstof	0,46	gemiddelde van alle waarden
100	waterstof	1,56	gemiddelde van alle waarden
200	waterstof	2,78	gemiddelde van alle waarden

Lek 1B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 1 - koppeling PE-Staal	30	33,67	31,84	1,83	62,4	0,90
2	stikstof	nr 1 - koppeling PE-Staal	30	32,75	30,79	1,96	63,3	0,95
3	stikstof	nr 1 - koppeling PE-Staal	30	33,31	31,40	1,91	62,5	0,94
4	stikstof	nr 1 - koppeling PE-Staal	30	32,92	30,61	2,31	71,2	1,00
6	stikstof	nr 1 - koppeling PE-Staal	30	34,88	32,92	1,96	61,1	0,98
7	waterstof	nr 1 - koppeling PE-Staal	30	31,07	27,32	3,75	64,3	1,80
8	waterstof	nr 1 - koppeling PE-Staal	30	31,20	27,49	3,71	63,3	1,80
9	waterstof	nr 1 - koppeling PE-Staal	30	30,97	27,58	3,39	61,2	1,71
10	waterstof	nr 1 - koppeling PE-Staal	30	31,03	27,52	3,51	65,7	1,65
11	waterstof	nr 1 - koppeling PE-Staal	30	30,87	27,64	3,23	63,4	1,57
12	aardgas	nr 1 - koppeling PE-Staal	30	31,09	28,92	2,17	62,5	1,07
11	aardgas	nr 1 - koppeling PE-Staal	30	31,95	29,63	2,32	62,2	1,15
12	aardgas	nr 1 - koppeling PE-Staal	30	32,13	29,59	2,54	62,2	1,25
13	aardgas	nr 1 - koppeling PE-Staal	30	32,01	29,49	2,52	61,1	1,27
14	aardgas	nr 1 - koppeling PE-Staal	30	31,75	29,10	2,65	63,4	1,29
15	aardgas	nr 1 - koppeling PE-Staal	30	31,83	29,17	2,66	61,1	1,34
14	aardgas	nr 1 - koppeling PE-Staal	30	31,62	29,08	2,54	61,0	1,28

Druk	Medium	Gemiddeld lek	
30	stikstof	0,95	gemiddelde van alle waarden
30	aardgas	1,23	gemiddelde van alle waarden
30	waterstof	1,70	gemiddelde van alle waarden

Lek 2A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 2 - klemkoppeling aftakzadel	100	106,7	104,9	1,8	75,4	0,68
2	stikstof	nr 2 - klemkoppeling aftakzadel	100	107,0	105,7	1,3	71,9	0,52
3	stikstof	nr 2 - klemkoppeling aftakzadel	100	105,4	104,1	1,3	69,8	0,53
4	stikstof	nr 2 - klemkoppeling aftakzadel	100	103,9	102,6	1,3	68,1	0,55
5	stikstof	nr 2 - klemkoppeling aftakzadel	100	102,8	101,5	1,3	75,4	0,49
6	stikstof	nr 2 - klemkoppeling aftakzadel	200	198,6	196,0	2,6	70,1	0,98
7	stikstof	nr 2 - klemkoppeling aftakzadel	200	198,0	195,4	2,6	70,5	0,98
8	stikstof	nr 2 - klemkoppeling aftakzadel	200	197,3	194,5	2,8	71,3	1,04
9	stikstof	nr 2 - klemkoppeling aftakzadel	200	197,6	195,4	2,2	69,4	0,84
10	stikstof	nr 2 - klemkoppeling aftakzadel	200	194,2	192,1	2,1	76,8	0,73
11	stikstof	nr 2 - klemkoppeling aftakzadel	200	197,3	194,7	2,6	70,8	0,97
12	stikstof	nr 2 - klemkoppeling aftakzadel	30	35,40	34,80	0,60	73,5	0,25
13	stikstof	nr 2 - klemkoppeling aftakzadel	30	34,65	33,96	0,69	75,4	0,28
14	stikstof	nr 2 - klemkoppeling aftakzadel	30	33,62	32,99	0,63	71,1	0,27
15	stikstof	nr 2 - klemkoppeling aftakzadel	30	35,70	35,17	0,53	81,6	0,20
16	stikstof	nr 2 - klemkoppeling aftakzadel	30	35,09	34,75	0,34	75,8	0,14

Druk	Medium	Gemiddeld lek	
30	stikstof	0,25	1 meest afwijkende waarde niet meegenomen
100	stikstof	0,52	1 meest afwijkende waarde niet meegenomen
200	stikstof	0,92	gemiddelde van alle waarden

Lek 2A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr 2 - klemkoppeling aftakzadel	100	105,0	103,2	1,8	81,8	0,63
2	aardgas	nr 2 - klemkoppeling aftakzadel	100	102,8	101,2	1,6	83,2	0,55
3	aardgas	nr 2 - klemkoppeling aftakzadel	100	104,2	102,8	1,4	88,1	0,46
4	aardgas	nr 2 - klemkoppeling aftakzadel	100	102,5	101,2	1,3	86,6	0,43
5	aardgas	nr 2 - klemkoppeling aftakzadel	100	100,7	98,7	2,0	85,0	0,68
6	aardgas	nr 2 - klemkoppeling aftakzadel	100	104,3	102,7	1,6	74,3	0,62
7	aardgas	nr 2 - klemkoppeling aftakzadel	200	193,7	190,9	2,8	63,5	1,17
8	aardgas	nr 2 - klemkoppeling aftakzadel	200	190,2	187,3	2,9	64,1	1,20
9	aardgas	nr 2 - klemkoppeling aftakzadel	200	194,5	191,2	3,3	65,0	1,35
10	aardgas	nr 2 - klemkoppeling aftakzadel	200	193,6	190,3	3,3	61,2	1,43
11	aardgas	nr 2 - klemkoppeling aftakzadel	200	194,2	191,3	2,9	66,3	1,16
12	aardgas	nr 2 - klemkoppeling aftakzadel	30	33,60	32,64	0,96	70,1	0,42
13	aardgas	nr 2 - klemkoppeling aftakzadel	30	32,16	31,13	1,03	67,7	0,47
14	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,81	29,70	1,11	61,9	0,55
15	aardgas	nr 2 - klemkoppeling aftakzadel	30	34,18	33,08	1,10	61,1	0,55
16	aardgas	nr 2 - klemkoppeling aftakzadel	30	32,75	31,64	1,11	62,1	0,55

Druk	Medium	Gemiddeld lek	
30	aardgas	0,53	gemiddelde van laatste 4 waarden
100	aardgas	0,56	gemiddelde van alle waarden
200	aardgas	1,26	gemiddelde van alle waarden

Lek 2A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr 2 - klemkoppeling aftakzadel	100	105,0	101,9	3,1	61,3	1,45
2	waterstof	nr 2 - klemkoppeling aftakzadel	100	101,0	98,0	3,0	63,2	1,36
3	waterstof	nr 2 - klemkoppeling aftakzadel	100	104,0	101,0	3,0	65,3	1,32
4	waterstof	nr 2 - klemkoppeling aftakzadel	100	104,5	101,5	3,0	63,4	1,36
6	waterstof	nr 2 - klemkoppeling aftakzadel	200	100,9	98,0	3,0	67,5	1,26
7	waterstof	nr 2 - klemkoppeling aftakzadel	200	104,0	101,0	3,0	57,9	1,49
8	waterstof	nr 2 - klemkoppeling aftakzadel	200	191,0	185,4	5,6	62,8	2,38
9	waterstof	nr 2 - klemkoppeling aftakzadel	200	190,4	184,7	5,7	61,9	2,46
10	waterstof	nr 2 - klemkoppeling aftakzadel	200	191,1	185,6	5,5	62,1	2,36
11	waterstof	nr 2 - klemkoppeling aftakzadel	200	191,0	185,2	5,8	62,7	2,47
12	waterstof	nr 2 - klemkoppeling aftakzadel	200	191,8	186,6	5,2	64,5	2,15
13	waterstof	nr 2 - klemkoppeling aftakzadel	30	33,90	32,83	1,1	63,2	0,52
14	waterstof	nr 2 - klemkoppeling aftakzadel	30	32,66	31,35	1,3	67,8	0,59
15	waterstof	nr 2 - klemkoppeling aftakzadel	30	34,02	32,90	1,1	62,0	0,55
16	waterstof	nr 2 - klemkoppeling aftakzadel	30	32,46	31,54	0,9	62,4	0,45

Druk	Medium	Gemiddeld lek	
30	waterstof	0,53	gemiddelde van alle waarden
100	waterstof	1,37	gemiddelde van alle waarden
200	waterstof	2,36	gemiddelde van laatste 5 waarden

Lek 2B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 2 - klemkoppeling aftakzadel	30	30,5	27,69	2,84	62,0	1,41
2	stikstof	nr 2 - klemkoppeling aftakzadel	30	30,4	27,36	3,02	61,2	1,52
3	stikstof	nr 2 - klemkoppeling aftakzadel	30	30,5	27,05	3,49	60,0	1,79
4	stikstof	nr 2 - klemkoppeling aftakzadel	30	30,1	27,11	2,96	63,4	1,44
5	stikstof	nr 2 - klemkoppeling aftakzadel	30	30,5	27,54	2,93	61,1	1,47
6	stikstof	nr 2 - klemkoppeling aftakzadel	100	102,0	93,6	8,4	62,1	3,91
7	stikstof	nr 2 - klemkoppeling aftakzadel	100	100,9	92,6	8,3	60,8	3,95
8	stikstof	nr 2 - klemkoppeling aftakzadel	100	102,0	93,7	8,3	61,0	3,93
9	stikstof	nr 2 - klemkoppeling aftakzadel	100	102,0	93,6	8,4	61,0	4,00
10	stikstof	nr 2 - klemkoppeling aftakzadel	100	101,7	93,6	8,1	60,9	3,85

Druk	Medium	Gemiddeld lek	
30	stikstof	1,52	gemiddelde van alle waarden
100	stikstof	3,93	gemiddelde van alle waarden

Lek 2B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,61	25,72	4,89	61,0	2,47
2	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,73	25,79	4,94	61,0	2,49
3	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,78	25,40	5,38	61,1	2,71
4	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,92	25,87	5,05	61,5	2,53
5	aardgas	nr 2 - klemkoppeling aftakzadel	30	30,48	24,96	5,52	59,9	2,84
6	aardgas	nr 2 - klemkoppeling aftakzadel	30	100,8	88,92	11,88	61,1	5,64
7	aardgas	nr 2 - klemkoppeling aftakzadel	100	100,3	88,41	11,89	61,0	5,66
8	aardgas	nr 2 - klemkoppeling aftakzadel	100	100,4	88,02	12,38	60,1	5,98
9	aardgas	nr 2 - klemkoppeling aftakzadel	100	100,5	87,95	12,55	60,3	6,04
10	aardgas	nr 2 - klemkoppeling aftakzadel	100	100,7	87,94	12,76	60,5	6,12

Druk	Medium	Gemiddeld lek	
30	aardgas	2,61	gemiddelde van alle waarden
100	aardgas	5,89	gemiddelde van alle waarden

Lek 2B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,84

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr 2 - klemkoppeling aftakzadel	30	30,89	25,56	5,33	49,9	3,29
2	waterstof	nr 2 - klemkoppeling aftakzadel	30	30,58	25,48	5,10	44,2	3,55
3	waterstof	nr 2 - klemkoppeling aftakzadel	30	30,91	25,58	5,33	46,9	3,50
4	waterstof	nr 2 - klemkoppeling aftakzadel	30	31,04	25,94	5,10	49,8	3,15
6	waterstof	nr 2 - klemkoppeling aftakzadel	30	30,80	25,48	5,32	48,0	3,41
7	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,8	90,2	10,6	30,5	10,06
8	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,7	90,0	10,7	31,9	9,70
9	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,9	90,1	10,9	32,0	9,84
10	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,8	90,2	10,6	30,1	10,20
11	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,6	90,0	10,6	29,5	10,45
12	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,9	80,0	20,9	61,1	10,01
13	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,9	80,3	20,6	61,1	9,86
14	waterstof	nr 2 - klemkoppeling aftakzadel	100	100,4	80,0	20,4	59,9	9,96

Druk	Medium	Gemiddeld lek	
30	waterstof	3,38	gemiddelde van alle waarden
100	waterstof	10,01	gemiddelde van alle waarden

Lek 3A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,7	102,6	1,1	67,8	0,43
2	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	102,3	101,4	0,9	64,3	0,37
3	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	102,2	100,8	1,4	59,9	0,62
4	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	101,3	99,8	1,5	61,0	0,66
5	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	101,3	99,8	1,5	59,8	0,67
6	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	101,3	100,0	1,3	66,5	0,52
7	stikstof	nr 3 - afdichtingsring aftakzadel-HL	200	196,8	193,7	3,1	68,7	1,10
8	stikstof	nr 3 - afdichtingsring aftakzadel-HL	200	195,4	192,3	3,1	63,6	1,19
9	stikstof	nr 3 - afdichtingsring aftakzadel-HL	200	195,0	192,3	2,7	60,5	1,09
10	stikstof	nr 3 - afdichtingsring aftakzadel-HL	200	195,0	192,4	2,6	62,6	1,02
11	stikstof	nr 3 - afdichtingsring aftakzadel-HL	200	195,0	192,3	2,7	60,6	1,09
12	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	34,76	34,18	0,58	62,7	0,26
13	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	34,11	33,66	0,45	61,9	0,21
14	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	33,52	32,99	0,53	60,8	0,25
15	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	32,97	32,13	0,84	62,0	0,38
16	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	32,06	31,52	0,54	61,1	0,25

Druk	Medium	Gemiddeld lek	
30	stikstof	0,27	gemiddelde van alle waarden
100	stikstof	0,54	gemiddelde van alle waarden
200	stikstof	1,10	gemiddelde van alle waarden

Lek 3A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	104,0	101,9	2,1	62,1	0,90
2	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	103,6	102,0	1,6	63,1	0,67
3	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	103,5	101,7	1,8	61,1	0,78
4	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	103,0	101,5	1,5	65,5	0,61
5	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	103,0	101,6	1,4	69,4	0,53
6	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	103,1	101,4	1,7	62,8	0,72
7	aardgas	nr 3 - afdichtingsring aftakzadel-HL	200	194,0	190,8	3,2	63,8	1,23
8	aardgas	nr 3 - afdichtingsring aftakzadel-HL	200	194,0	191,1	2,9	61,1	1,16
9	aardgas	nr 3 - afdichtingsring aftakzadel-HL	200	194,0	191,0	3,0	62,2	1,18
10	aardgas	nr 3 - afdichtingsring aftakzadel-HL	200	194,0	190,7	3,3	66,2	1,22
11	aardgas	nr 3 - afdichtingsring aftakzadel-HL	200	194,2	191,0	3,2	62,1	1,26
12	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,50	30,23	0,27	66,7	0,11
13	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	31,17	31,19	-0,02	62,0	-0,01
14	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	31,22	31,15	0,07	63,0	0,03
15	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	31,20	30,93	0,27	63,2	0,12
16	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,91	30,86	0,05	61,0	0,02

Druk	Medium	Gemiddeld lek	
30	aardgas	0,12	gemiddelde van 2 hoogste waarden
100	aardgas	0,70	gemiddelde van alle waarden
200	aardgas	1,21	gemiddelde van alle waarden

Lek 3A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	102,8	99,8	3,0	61,0	1,30
2	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,0	100,1	2,9	61,6	1,25
3	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	102,7	99,2	3,5	61,0	1,51
4	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,1	100,0	3,1	60,3	1,36
5	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,0	99,4	3,6	62,2	1,52
6	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,2	99,5	3,7	60,0	1,65
	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	103,0	99,7	3,3	61,2	1,41
7	waterstof	nr 3 - afdichtingsring aftakzadel-HL	200	197,0	191,3	5,7	62,2	2,24
8	waterstof	nr 3 - afdichtingsring aftakzadel-HL	200	197,0	191,1	5,9	61,1	2,36
9	waterstof	nr 3 - afdichtingsring aftakzadel-HL	200	197,0	190,9	6,1	59,7	2,50
10	waterstof	nr 3 - afdichtingsring aftakzadel-HL	200	197,0	191,2	5,8	61,5	2,31
11	waterstof	nr 3 - afdichtingsring aftakzadel-HL	200	197,0	190,9	6,1	64,2	2,33
12	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	33,93	32,81	1,12	60,0	0,53
13	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	32,02	31,05	0,97	61,5	0,45
14	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	31,00	30,38	0,62	61,2	0,29
15	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	32,00	31,17	0,83	61,3	0,38
16	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	31,00	30,11	0,89	60,9	0,41

Druk	Medium	Gemiddeld lek	
30	waterstof	0,41	gemiddelde van alle waarden
100	waterstof	1,43	gemiddelde van alle waarden
200	waterstof	2,35	gemiddelde van alle waarden

Lek 3B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	32,02	29,69	2,33	60,6	1,09
2	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,25	28,08	2,17	63,1	0,97
3	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,28	28,00	2,28	58,8	1,10
4	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	29,72	27,54	2,18	66,2	0,93
5	stikstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,26	28,02	2,24	56,5	1,12
6	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,4	93,6	6,8	61,3	2,97
7	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,4	93,5	6,9	60,8	3,04
8	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,7	93,7	7,0	61,1	3,07
9	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,8	93,6	7,3	62,2	3,11
10	stikstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,5	93,5	7,0	61,0	3,05

Druk	Medium	Gemiddeld lek	
30	stikstof	1,04	gemiddelde van alle waarden
100	stikstof	3,05	gemiddelde van alle waarden

Lek 3B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,58	27,11	3,47	61,1	1,61
2	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,64	27,14	3,50	61,1	1,62
3	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,76	27,31	3,45	61,0	1,60
4	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,53	26,96	3,57	61,0	1,66
5	aardgas	nr 3 - afdichtingsring aftakzadel-HL	30	30,65	27,03	3,62	66,6	1,54
6	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	100,8	90,9	9,9	62,3	4,25
7	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	100,6	90,7	9,9	60,9	4,36
8	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	99,6	90,1	9,5	60,2	4,22
9	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	100,8	90,7	10,1	62,0	4,36
10	aardgas	nr 3 - afdichtingsring aftakzadel-HL	100	100,9	91,0	10,0	61,1	4,35

Druk	Medium	Gemiddeld lek	
30	aardgas	1,61	gemiddelde van alle waarden
100	aardgas	4,31	gemiddelde van alle waarden

Lek 3B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,14

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,32	25,08	5,24	60,4	2,46
2	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,16	24,82	5,34	62,3	2,44
3	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,58	25,39	5,19	61,0	2,42
4	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,34	25,27	5,07	61,1	2,35
5	waterstof	nr 3 - afdichtingsring aftakzadel-HL	30	30,41	25,34	5,07	61,1	2,35
6	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,1	84,3	15,8	60,2	7,06
7	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,6	84,6	16,0	60,0	7,15
8	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,5	84,2	16,3	61,0	7,18
9	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,5	84,3	16,2	62,2	7,00
10	waterstof	nr 3 - afdichtingsring aftakzadel-HL	100	100,9	85,0	15,9	61,1	7,00

Druk	Medium	Gemiddeld lek	
30	waterstof	2,40	gemiddelde van alle waarden
100	waterstof	7,08	gemiddelde van alle waarden

Lek 4A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	109,5	106,7	2,8	65,1	1,19
2	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	111,4	108,9	2,5	64,3	1,07
3	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	113,3	110,4	2,9	64,4	1,24
4	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,0	107,4	2,6	69,9	1,03
5	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,0	107,3	2,7	73,5	1,01
6	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,1	108,0	2,1	60,4	0,96
7	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,2	108,0	2,2	60,6	1,00
8	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	34,03	33,03	1,00	61,1	0,48
9	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	34,09	33,12	0,97	64,9	0,44
10	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	32,52	31,52	1,00	60,0	0,49
11	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	31,08	30,39	0,69	61,2	0,33
12	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	30,10	29,41	0,69	63,2	0,32
13	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	30,98	30,48	0,50	63,2	0,23
14	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	30,26	29,58	0,68	61,2	0,33
15	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	34,11	33,37	0,74	61,1	0,36
16	stikstof	nr. 4 - koppeling gaskraan en gasmeter	200	198,0	193,6	4,4	61,7	1,83
17	stikstof	nr. 4 - koppeling gaskraan en gasmeter	200	198,9	194,7	4,2	60,3	1,79
18	stikstof	nr. 4 - koppeling gaskraan en gasmeter	200	197,7	193,2	4,5	61,0	1,90
19	stikstof	nr. 4 - koppeling gaskraan en gasmeter	200	198,0	193,8	4,2	62,7	1,72
20	stikstof	nr. 4 - koppeling gaskraan en gasmeter	200	197,9	193,7	4,2	59,9	1,80

Druk	Medium	Gemiddeld lek	
30	stikstof	0,37	gemiddelde van alle waarden
100	stikstof	1,07	gemiddelde van alle waarden
200	stikstof	1,81	gemiddelde van alle waarden

Lek 4A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	186,9	5,1	61,6	2,14
2	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	191,9	186,9	5,0	61,0	2,12
3	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	191,9	186,9	5,0	61,0	2,12
4	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	186	6,0	68,3	2,27
5	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	186	6,0	60,8	2,55
6	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	185,8	6,2	60,7	2,64
7	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	186,6	5,4	60,9	2,29
8	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	192,0	187,3	4,7	60,8	2,00
9	aardgas	nr. 4 - koppeling gaskraan en gasmeter	200	191,9	186	5,9	62,4	2,44
10	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	109,9	105,7	4,2	76,1	1,53
11	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	110,0	106,7	3,3	62,2	1,46
12	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	110,00	107,1	2,9	60,0	1,34
13	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	110,00	107,1	2,9	62,7	1,28
14	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	110,00	107	3,0	61,3	1,35
15	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	110,00	107,1	2,9	62,1	1,29
16	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	32,15	31,30	0,85	61,5	0,41
17	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	32,00	31,36	0,64	62,4	0,30
18	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	32,00	31,35	0,65	62,4	0,31
19	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	32,25	31,36	0,89	62,2	0,42
20	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	31,89	31,00	0,89	60,5	0,44
21	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,12	32,41	0,71	61,0	0,34

Druk	Medium	Gemiddeld lek	
30	aardgas	0,37	gemiddelde van alle waarden
100	aardgas	1,38	gemiddelde van alle waarden
200	aardgas	2,28	gemiddelde van alle waarden

Lek 4A
Lek van ongeveer 1 l/h ingesteld met stikstof 100mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	36,10	34,92	1,18	63,2	0,55
2	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	34,51	33,27	1,24	61,3	0,60
3	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,01	31,76	1,25	67,9	0,54
4	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	31,52	30,55	0,97	61,1	0,47
5	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	30,45	29,69	0,76	63,0	0,36
6	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,45	32,32	1,13	60,9	0,55
	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	31,88	30,69	1,19	60,9	0,58
7	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,1	104,5	5,6	61,3	2,53
8	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,1	105,0	5,1	62,2	2,27
9	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,6	105,7	4,9	62,5	2,17
10	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,3	105,2	5,1	60,7	2,33
11	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	110,5	105,5	5,0	62,5	2,22
12	waterstof	nr. 4 - koppeling gaskraan en gasmeter	200	195,0	185,7	9,3	60,5	3,97
13	waterstof	nr. 4 - koppeling gaskraan en gasmeter	200	195,0	185,6	9,4	63,1	3,85
14	waterstof	nr. 4 - koppeling gaskraan en gasmeter	200	195,1	185,6	9,5	62,9	3,90
15	waterstof	nr. 4 - koppeling gaskraan en gasmeter	200	195,2	186,0	9,2	61,3	3,88
16	waterstof	nr. 4 - koppeling gaskraan en gasmeter	200	194,8	185,4	9,4	60,6	4,01

Druk	Medium	Gemiddeld lek	
30	waterstof	0,52	gemiddelde van alle waarden
100	waterstof	2,30	gemiddelde van alle waarden
200	waterstof	3,92	gemiddelde van alle waarden

Lek 4B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	30,16	28,48	1,7	61,1	0,82
2	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,29	31,42	1,9	61,0	0,91
3	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,21	31,39	1,8	61,0	0,88
4	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,01	31,17	1,8	61,1	0,89
5	stikstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,12	31,26	1,9	61,1	0,90
6	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	102,0	97,5	4,5	61,5	2,04
7	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	104,0	98,9	5,1	70,0	2,03
8	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	104,0	99,3	4,7	60,2	2,18
9	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	103,9	99,2	4,7	60,4	2,17
10	stikstof	nr. 4 - koppeling gaskraan en gasmeter	100	104,0	99,2	4,8	61,0	2,19

Druk	Medium	Gemiddeld lek	
30	stikstof	0,88	gemiddelde van alle waarden
100	stikstof	2,12	gemiddelde van alle waarden

Lek 4B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,03	30,58	2,45	60,2	1,21
2	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,04	30,28	2,76	61,3	1,34
3	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,00	30,34	2,66	61,1	1,29
4	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,10	30,57	2,53	62,1	1,21
5	aardgas	nr. 4 - koppeling gaskraan en gasmeter	30	33,00	30,39	2,61	62,2	1,24
6	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	104,9	98,3	6,6	61,7	2,98
7	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	104,9	98,2	6,7	61,0	3,06
8	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	104,8	98,2	6,6	61,0	3,01
9	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	104,4	97,1	7,3	66,3	3,07
10	aardgas	nr. 4 - koppeling gaskraan en gasmeter	100	105,1	98,1	7,0	64,2	3,04

Druk	Medium	Gemiddeld lek	
30	aardgas	1,26	gemiddelde van alle waarden
100	aardgas	3,03	gemiddelde van alle waarden

Lek 4B
Lek van ongeveer 1 l/h ingesteld met stikstof 30mbar

Volume (l)	8,68

Nr	Medium	Omschrijving lek	Instelling nominale druk (mbar)	P start (mbar)	P eind (mbar)	Daling (mbar)	Tijdsduur (s)	Debiet (l/h)
1	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	104	92,2	11,8	60,4	5,48
2	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	105,9	94,1	11,8	60,1	5,49
3	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	104,8	93	11,8	60,2	5,50
4	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	105	93,3	11,7	59,9	5,47
5	waterstof	nr. 4 - koppeling gaskraan en gasmeter	100	104,6	92,4	12,2	60,5	5,64
6	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,12	29,02	4,1	61	2,00
7	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,14	29,15	3,99	61,2	1,94
8	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,16	29,1	4,06	61,3	1,97
9	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,09	28,84	4,25	60	2,10
10	waterstof	nr. 4 - koppeling gaskraan en gasmeter	30	33,07	28,84	4,23	61,1	2,05

Druk	Medium	Gemiddeld lek	
30	waterstof	2,01	gemiddelde van alle waarden
100	waterstof	5,52	gemiddelde van alle waarden

VII Measuring equipment used

Description	Manufacturer and type	Kiwa no.
Pressure gauge (100 and 200 mbar)	Digitron B2022P	112066
Pressure gauge (30 mbar and P atm)	Euro Index BlueLine S4602	113805
Temperature gauge	Mera	112412
Balance scale (to determine volume of test set-up)	Mettler Toledo SR32001	111603