Clean Hydrogen Partnership

Testing **Hy**drogen admixture for **G**as **A**pplications

Work Package 3 – Task 3.2.3 - Leakage tests on indoor installation (long term)

Non-combustion related impact of hydrogen admixture – Tightness testing of gas distribution components in $40\%H_2+60\%CH_4$

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Executive summary

In the context of reaching the objective of European decarbonisation, the use of hydrogen as an energy vector seems to be one of the ways to decrease Europe dependency on fossil fuels. Hence, the question of the use and transport of hydrogen is raised. THyGA addresses the conversion of the gas distribution network from natural gas to hydrogen and natural gas blends and investigates the technical impacts on residential and commercial gas appliances, as well as gas distribution components.

The present work is concerned with the evaluation of the tightness of the components located on domestic and commercial gas lines from the gas meter to the end user appliance, in presence of a mixture 40%H_2+60%CH_4 at 35 mbar. The objective of the test is to be able to conclude on being to be as close as possible to the service condition - for that reason we are actually testing with a "safety margin" (so 35 mbar instead of 20 and 40% H2 instead of 20%). The components were taken from installations being used currently in Germany, Denmark, Belgium and France. The current standard methods to evaluate natural gas distribution tightness propose testing duration of several minutes [1]. In this work, the components tightness was first evaluated using such standard methods before carrying out tests on longer period of time and evaluate the potential influence of time.

The results were compared to the current admissible leakage rates for natural gas in the gas distribution network: 1 $l.h^{-1}$ according to the NEN 7244-7 standard [2] and in appliances: 0.1 $l.h^{-1}$ according to the EN 30-1-1:2021 standard [3] for cooking appliances burning gas. Generally, none of the leakage rates obtained on the short and long term tests were above the admissible leakage rates of the NEN 7244-7, and EN 30-1-1:2021 standards. Hence, once a gas line is properly installed, following natural gas standards at low pressures (35 mbar), **it can be expected that it will be tight for the gas blend**. Furthermore, the review and comparison of other projects results addressing tightness of gas distribution network/components in 100%H_2 was added, enabling the formulation of recommendations on testing methods.

List of abbreviations

NG	Natural gas
H_2NG	Hydrogen / Natural Gas blend
He	Helium

Table of contents

1 Introduction

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2 Background

In order to estimate the differences of leakage rates between methane and hydrogen, flow theory can be used. In the case of continuum flow, four regimes describe how a gas can escape from a pressurised pipe. From high to low pressures they are: shocked flow, subsonic flow, turbulent flow and laminar flow regimes [4], [5]. The main factors inducing one flow regime or another are the following: the pressure in the pipe, the gas properties (density, viscosity), leakage characteristic (geometry, size, crack length…). Harwood et al. [4] as well as Roberts et al. [5] in the projects H21 and Hy4Heat, have respectively determined the ratios of flow rate of hydrogen compared to the flow rate of methane for the different regimes, using equation analysis of the flow through a hole. It appears that, when the flow is turbulent (shoked, subsonic and turbulent regimes) the ratio set between 2.9 and 2.8. In laminar conditions however, this ratio is reduced to 1.2. As the gas flow is regular and smooth, essentially at low pressures, the difference between leakage rates in methane and hydrogen decreases.

Using various approaches, national and European projects have investigated the issue of potentially higher hydrogen leakage rates compare to current admissible methane leakage rates on the gas distribution networks [4], [6]–[8]. A Ukrainian consortium held by Ivano-Frankivsk National Technical University of Oil and Gas and Naftogazbudinformatyka Ltd. In collaboration with RGC (Regional Gas Company), built five entire gas network models on five different RGC sites and tested them in outdoor conditions. In the Dutch project HyDelta, KIWA Technology have investigated the tightness of 4 coupling types (PE-steel, clamp-screw coupling, sealing ring between saddle and main pipe, gas meter inlet valve) in which they created controlled leaks and compared the leakage rates of methane and hydrogen. The UK project H21, tested both commercial burners and gas distribution parts in NG and 100%H_2. Despite discrepancy in the testing methodologies: evaluating an entire gas network or one coupling after the other; carrying on tests in a lab or outdoor; short or long tests duration; main common findings on these different studies can be drawn:

- If no leaks were detected in CH_4, no leaks were detected in H_2.

- At low pressures (a few mbar):
    - the temperature has a large influence on the pressure evolution;
    - leakage rates in H_2 and CH_4 were close to each other.
- Generally, tests at low pressure (a few mbar) lead to inaccurate results and difficulty to differentiate between the presence of leaks or the influence of the temperature

In the current work, the objective of the leakage tests was to evaluate the tightness of gas distribution components to a gas blend composed of 40%H_2 + 60%CH_4 and its potential evolution on a long time periods (i.e., weeks). For this purpose, collected components were joined together to build 10 lines that were tested under short tests first (i.e., 10 minutes) in He, Air and H_2NG blend following standard procedures, and then long term tests were then carried (i.e., weeks) with H_2NG blend.

The results were compared to the current admissible leakage rates of the gas distribution network within buildings. The investigated components included parts of the gas distribution network along the gas pipeline in the domestic household up to the appliances, including gas meter, valves, different materials components as well as burners. In Europe, the admissible NG leakage rates on the gas distribution varies from a country to another. The appliances follow more conservative leakage rates [9]. Hence, two references were chosen: NEN 7244-7 standard [2] for gas distribution: 1 $l.h^{-1}$ at the maximum operating pressure, and the EN 30-1-1:2021 standard [3] dedicated to gas fire heat boiler: 0.1 $l.h^{-1}$ at a testing pressure of 50 mbar for boilers which do not use third family gas and 150 mbar for boilers which do use third family gas.

3 Experimental methods

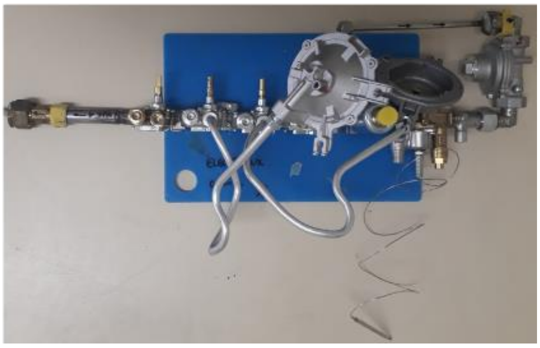
3.1 Description of the lines

The lines tested were composed of gas grid components extracted (taken from real installations) from the European distribution network. They were provided by THYGA partners: DGC (Denmark), ENGIE (France), GWI (Germany) and DVGW.EBI (Germany). A description of the components provided by DGC (D1 to D26) is given in Annex 1. The components were assembled together using fittings to make ten lines, Table 1. In order to test the entire lengths of the lines the valves were tested in their open position.

Table 1 : Composition of the ten lines, the components D1 to D26 belongs to DGC and are described in Annexe 1.

Line number	Components
1	Electrolux appliances part
2	D6, D23 (DGC)
3	Gas meter, D5 (DGC), gas valve connected to Cu tubing, yellow valve (ENGIE)
4	Flexible inox and Cu tubing, green valve (GWI and DVGW.EBI), D15, D22 (DGC)
5	D7, D21 (DGC), gas meter (GWI and DVGW.EBI), brass tube (GWI and DVGW.EBI)
6	Gas meter + yellow tubing + Cu tubing + green valve (GWI and DVGW.EBI) D24 (DGC)
7	D14, D25 (DGC), yellow valve and Cu tube.
8	D9, D10, D19 (DGC)
9	D26, D13 (DGC)
10	D11, D17, D18 (DGC)

N°1



N°2

N°3

N°4

N°5

N°6

N°7

N°8

N°9

N°10

Figure 1 : Images of the 10 lines tested.

3.2 Measurement of the lines volume

In order to determine the leakage flow in the lines, it was necessary to measure their inner gas volume. This was carried out using a capacity with a known volume ($V_C = 1.28$ l). The gas pressure in the capacity and the lines were monitored. The capacity was connected to the line by a manual gas valve. The capacity was filled with air above the test pressure; once the pressure is stabilised, the valve between the capacity and the line was opened, enabling the line to be filled with the gas contained in the capacity. Knowing the equilibrium pressure, it was possible to calculate the volume of the line using the equation of the perfect gas, as described in Figure 2 (assuming there is no major leaks). Table 2 gives the terminology for the symbols used in the calculation.

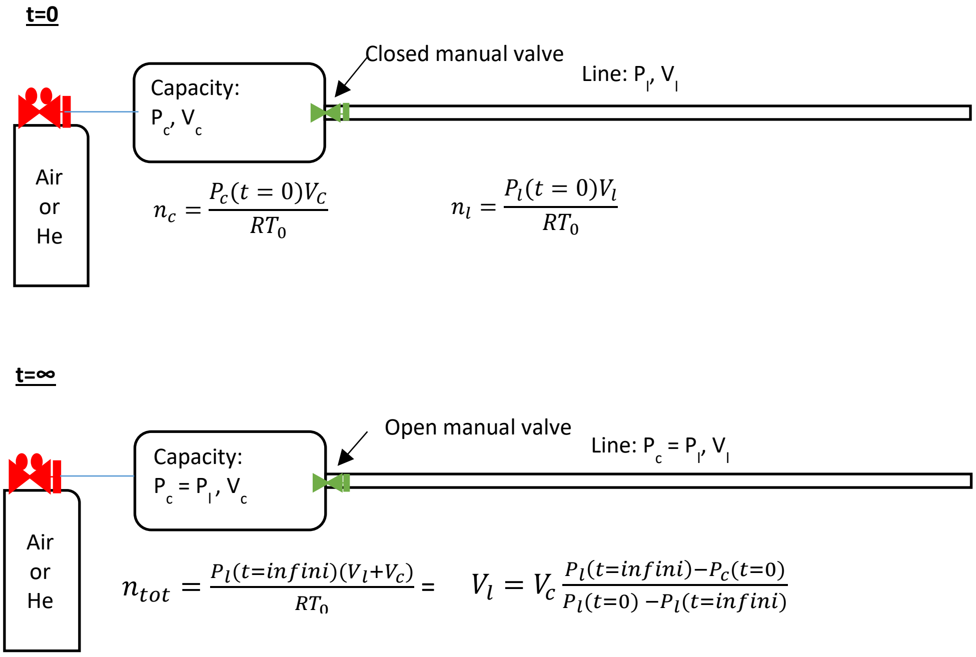


Figure 2 : Scheme presenting the set up used to estimate the volume of the gas lines.

Table 2 : Nomenclature used in the equations used to determine the volume of the lines.

P_c	Pressure in the capacity
P_l	Pressure in the line
V_c	Volume of the capacity
V_l	Volume of the line
n_c	Number of moles of gas in the capacity at t=0
n_l	Number of moles of gas in the line at t=0
n_{tot}	Number of moles of gas in the system (capacity + line) at t=0
R	Gas constant
T	Temperature

3.3 Measurement of the lines tightness

The lines tightness was evaluated through lock-off tests: measure of the pressure decay with an initial pressure (P_{ini}) of 35 mbar. For small flows, this type of tests is preferred to the measurement of the flow necessary to maintain a constant pressure using a flow meter, as the flow can be too small to be controlled. The initial pressure was chosen to be as close as possible to the service conditions. Short- and long-term tests were carried on this way. The short-term tests were performed in air, in He and in H_2NG blend, assimilated as 40% H_2 + 60% CH_4, and the long-term test in the H_2NG blend. It is well-known that the temperature has a large influence on the gas pressure, hence, the temperature of the lines was recorded during all the tests using thermocouple fixed on the external wall of the lines.

The short tests were carried out according to the NF DTU 61.1[1] standard. This method consists of the stabilisation of the pressure in the set up for 15 min followed by a record of the pressure for 10 min. Tests were repeated on the lines L1, L2 and L3 to evaluate the repeatability of this testing method. The results obtained were used to determine the pressure drop, independent of the temperature (ΔP_{leak}) and the leakage flow in the lines (φ_{leak}), using the perfect gas equation:

$$\Delta P_{tot} = \Delta P_T + \Delta P_{leak}$$

Equation 1

With ΔP_{tot}, the total pressure drop measured, ΔP_T the pressure evolution induced by the temperature and ΔP_{leak}, the pressure loss due to the presence of a potential leak.

$$\Delta P_{leak} = P_{ini} - P_{fin}\left(\frac{T_{ini}}{T_{fin}}\right) \qquad [\text{bar}]$$

Equation 2

With P_{ini} the initial pressure measured in the pipe, P_{fin} the pressure measured in the pipe at the end of the test.

$$V_{leak} = \left(\frac{n_{leak} RT}{P_a}\right) \qquad [\text{m}^3]$$

Equation 3

With, P_a the atmospheric pressure in Pa at T= 0°C, R the gas constant 8.314 $J.K^{-1}.mol^{-1}$ and

$$n_{leak} = n_{fin} - n_{ini} = \frac{V_l}{R}\left(\frac{P_{ini}}{T_{ini}} - \frac{P_{fin}}{T_{fin}}\right) \qquad [\text{mole}]$$

Equation 4

With V_l, the volume of the gas line.

Using Equation 4, the flow rate is calculated following the equation:

$$\varphi_{leak} = \frac{V_{leak}}{t} \qquad [\text{Nl.h}^{-1}]$$

Equation 5

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[1] Unified Technical Document used by installers in France

The long-term tests consist of 15 min of pressure stabilization in the lines, followed by measurement of the pressure decay for at least 10 days or up until there was no pressure in the lines anymore. Once the measurements were achieved, the leakage rates were compared to the standard admissible leakage rates.

4 Results

4.1 Lines volume

The results of the lines volumes are given in Table 3. Most of the lines volumes are inferior to one litre, apart from the lines 3, 5 and 6 which included gas meters. All the tests were carried out at a capacity pressure close to 35 mbar apart from the lines with a gas meter, which required higher pressure due to their larger volumes.

Table 3 : Measurements and resulting estimated volume for all the tested lines. The test were performed in air.

Line number	**Line description**	**Pcapa(t=0)**	**Pligne(t=0)**	**P(t=1)**	**estim. V_{line}**
		bar	bar	bar	litre
1	Electrolux components	1,034	0,987	1,028	0,18
2	Cu tube large Ø	1,034	0,987	1,012	1,15
3	With gas meter	1,275	0,991	1,070	3,32
4	With inox flexible	1,044	0,987	1,029	0,46
5	With gas meter	1,367	0,989	1,029	10,58
6	With gas meter	1,334	0,991	1,038	8,24
7	Cu tube	1,036	0,986	1,029	0,22
8	DGC components	1,028	0,989	1,014	0,74
9	DGC components	1,038	0,987	1,027	0,35
10	DGC components	1,026	0,987	1,016	0,42

4.2 Short term tests

First of all, the repeatability of the short tests was evaluated on the lines 1 and 2, in He and Air. Air is the gas used in service for the tightness testing and He is the harmless gas with the closest characteristics to H_2 (low density). For this purpose, 3 consecutive short tests were performed on each line, with a purge of the line in between. The results, Table 4 and Table 6, show that the leakage flow rates were very small (<< 0.1 $l.h^{-1}$), furthermore no distinction between the leakage rates of He and Air was observed. Finally, the leakage rates obtained on line 1 were not repeatable while the ones on the line 2 showed regular results. This might be due to the very low volume of gas of line 1 compared to line 2 which could induce non accurate results as well as to the very low flow rates measured.

The results of the short tests are given in Table 7, Table 8 and Table 9. All the flow rates obtained in He, Air and gas blend are well below the 0.1 $l.h^{-1}$ admissible flow rates of the NF DTU 61.1 Part 3 [1] addressing the case of appliances. The results also show some negative leakage rates. As the calculation were made for the pressure drop to be independent of the temperature (Equation 1 to Equation 5), these were not physically explained.

Table 4 : Results of the short tests repeatability tests, line 1 (V_l =0.179 l)

	P1	**P2**	**T1**	**T2**	**ΔP, corrected with the temperature**	**n_{leak}**	**Leakage flow**
Line 1	*bar*	*bar*	*°C*	*°C*	*mbar*	*mole,* x 10-6	*Nl.h^{-1}, x 10-4*
He	1,029	1,028	21,20	21,12	0,634	**4,64**	**6,24**
	1,035	1,034	21,16	21,36	1,902	**13,93**	**18,72**
	1,031	1,030	21,27	21,38	1,277	**9,35**	**12,57**
Air	1,032	1,030	21,02	20,76	0,645	**4,73**	**6,36**
	1,029	1,029	20,70	20,66	0,720	**5,28**	**7,10**
	1,030	1,029	21,00	21,13	1,358	**9,95**	**13,38**

Table 5 : Results of the short tests repeatability tests, line 2 (V_l =1.150 l)

	P1	**P2**	**T1**	**T2**	**ΔP, corrected with the temperature**	**n_{leak}**	**Leakage flow**
Line 2	*bar*	*bar*	*°C*	*°C*	*mbar*	*mole,* x 10^{-6}	*Nl.h^{-1}, x 10^{-4}*
He	1,029	1,029	21,40	21,39	0,423	**19,85**	**26,68**
	1,029	1,029	21,35	21,35	0,157	**7,38**	**9,91**
	1,034	1,034	21,35	21,35	0,181	**8,48**	**11,40**
Air	1,033	1,032	20,68	20,71	0,318	**25,55**	**34,34**
	1,033	1,033	20,71	20,64	0,362	**-3,84**	**-5,16**
	1,031	1,031	20,79	20,73	0,231	**-9,94**	**-13,36**

Table 6 : Results of the short tests in He for the 10 lines.

Line number	**Line volume**	**P1**	**P2**	**T1**	**T2**	**ΔP, mbar**	**n_{leak}**	**Leakage flow**
	l	*bar*	*bar*	*°C*	*°C*	*mbar*	*mole,* x 10^{-6}	*Nl.h^{-1}, x 10^{-4}*
1	*0,18*	1,029	1,028	21,20	21,12	**0,63**	**4,64**	**6,24**
2	*1,15*	1,029	1,029	21,40	21,39	**0,42**	**19,85**	**26,68**
3	*3,32*	1,040	1,040	21,42	21,39	**-0,56**	**-76,38**	**-102,65**
4	*0,46*	1,03469	1,03516	20,76	20,68	**-0,75**	**-14,12**	**-18,98**
5	*10,58*	1,032	1,032	21,58	21,49	**-0,30**	**-130,37**	**-175,21**
6	*8,24*	1,032	1,032	21,45	21,56	**0,39**	**132,11**	**177,56**
7	*0,22*	1,031	1,031	21,23	21,23	**0,30**	**2,74**	**3,69**
8	*0,74*	1,032	1,032	20,77	20,87	**0,29**	**8,96**	**12,04**
9	*0,35*	1,031	1,031	20,17	20,26	**0,40**	**5,87**	**7,90**
10	*0,42*	1,029	1,029	21,30	21,40	**0,48**	**8,24**	**11,07**

Table 7 : Results of the short tests in Air for the 10 lines.

Line number	**Line volume**	**P1**	**P2**	**T1**	**T2**	**ΔP, mbar**	**n_{leak}**	**Leakage flow**
	l	*bar*	*bar*	*°C*	*°C*	*mbar*	*mole,* x 10^{-6}	*Nl.h^{-1}, x 10^{-4}*
1	*0,18*	1,032	1,030	21,02	20,76	0,62	**4,51**	**6,06**
2	*1,15*	1,033	1,032	20,71	20,68	0,32	**14,95**	**20,10**
3	*3,32*	1,035	1,035	21,43	21,42	-0,06	**-8,70**	**-11,69**
4	*0,46*	1,038	1,039	20,25	20,48	0,10	**1,90**	**2,55**
5	*10,58*	1,035	1,035	21,48	21,47	-0,20	**-86,29**	**-115,97**
6	*8,24*	1,035	1,034	21,42	21,37	-0,10	**-32,84**	**-44,14**
7	*0,22*	1,032	1,032	21,35	21,35	-0,14	**-1,29**	**-1,73**
8	*0,74*	1,032	1,032	20,38	20,69	0,92	**28,00**	**37,63**
9	*0,35*	1,031	1,031	20,17	20,26	0,40	**5,87**	**7,90**
10	*0,42*	1,033	1,033	21,50	21,51	-0,07	**-1,25**	**-1,68**

Table 8 : Results of the short tests gas blend (60% CH_4 + 40% H_2) for the 10 lines.

Line number	**Line volume**	**P1**	**P2**	**T1**	**T2**	**ΔP, mbar**	**n_{leak}**	**Leakage flow**
	l	*bar*	*bar*	*°C*	*°C*	*mbar*	*mole,* x 10^{-6}	*Nl.h^{-1}, x 10^{-4}*
1	*0,18*	-	-	-	-	-	**-**	-
2	*1,15*	-	-	-	-	-	**-**	-
3	*3,32*	1,032	1,032	21,32	21,32	-0,05	**-7,34**	**-9,86**
4	*0,46*	1,033	1,033	21,00	20,96	-0,45	**-8,44**	**-11,34**
5	*10,58*	1,033	1,033	21,43	21,45	-0,04	**-17,90**	**-24,05**
6	*8,24*	1,033	1,033	21,51	21,59	0,25	**82,96**	**111,50**
7	*0,22*	1,033	1,033	21,44	21,57	0,35	**3,16**	**4,24**
8	*0,74*	1,034	1,033	21,05	21,01	0,06	**1,93**	**2,59**
9	*0,35*	1,030	1,030	21,22	21,11	-0,19	**-2,83**	**-3,80**
10	*0,42*	1,030	1,030	21,35	21,48	0,48	**8,36**	**11,24**

4.3 Long-term tests

Figure 3 presents the long-term tests results for line 1 to 10. The graphs present the pressure and temperature evolution according to the time. For all the lines, the pressure tends to vary according to the temperature. Lines 1, 2, 3, 6, 8 and 9 present a pressure drop and reached the atmospheric pressure, P_a, after about 52, 90, 70, 250, 100 and 70 hours respectively. Lines 4, 5, 7 and 10 present a pressure evolution very close to the evolution of the temperatures.

It is possible to estimate the pressure evolution considering only the effect of the temperature without leakage. For this model, the following assumption are made:

- The gas blend is considered as a unique gas;
- The gas blend follows the equation of the perfect gases;
- The quantity of gas in the line is conserved (i.e. no leak).

Hence, the pressure evolution of the pressure is given by the following equation:

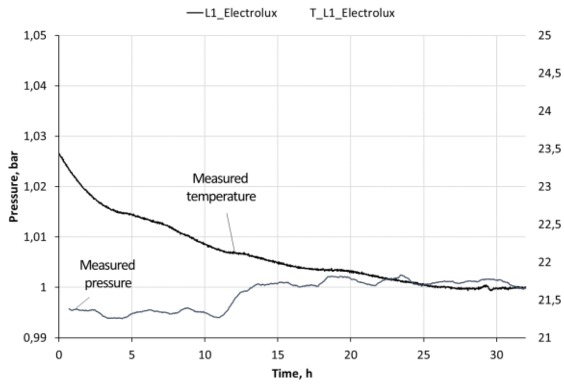
$$P_{ev} = P_{ini} \frac{T_{ev}}{T_{ini}}$$

Equation 6

The evolution of the initial pressure (P_{ini}) induced by the temperature only was calculated and added on Figure 3 (yellow curves).

For line 3 and line 6, the gap between the calculated pressure and the measured pressure increases with time, confirming the presence of a leak. The calculated pressure evolution of line 4 presents a growing gap with the measured pressure which, if the assumptions were corrects, highlighted a small leak. On the graphs for the lines line 5, 7 and 10 however, no growing gap appears between the calculated and the measured pressure. Those lines are tight to the gas blend.

A summary of the long-term tests is given in Table 9. The results show that the leakage rates recorded are well below the current admissible leakage rates. Negative leakage rates were also observed on the long-term tests. They could be explained by the uncertainties in the measurements and the assumptions made on the flow calculations (perfect gas equation, ...).



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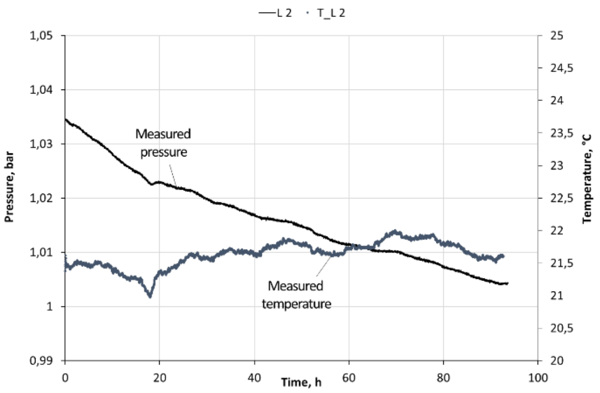

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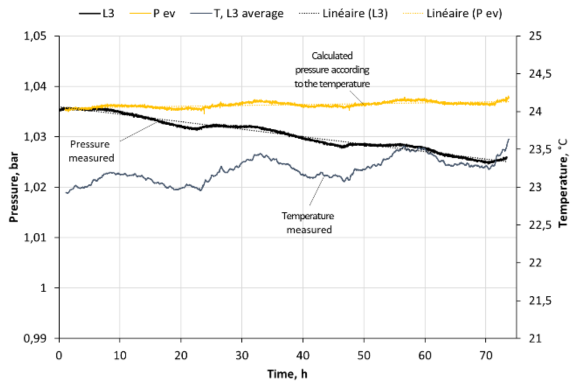

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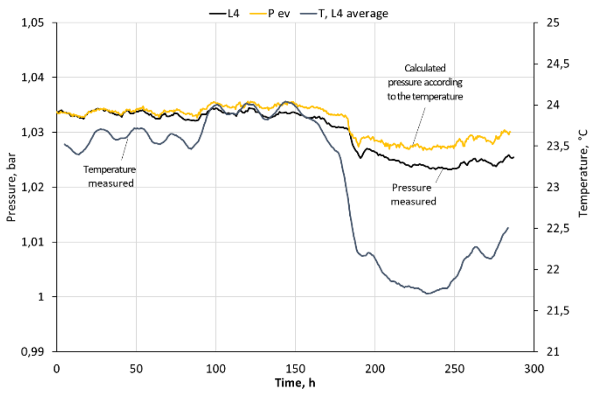

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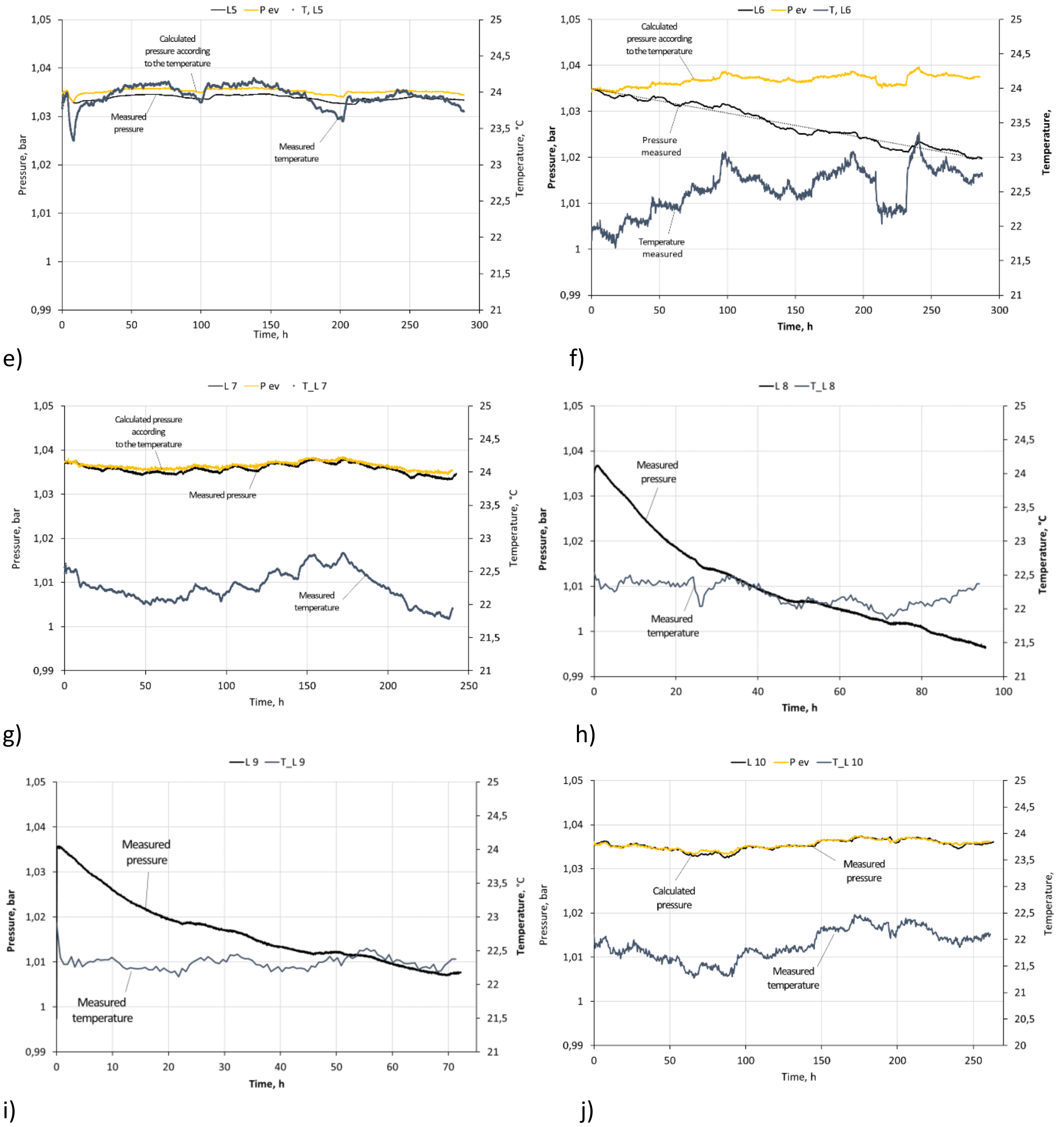

Figure 3 : Results of the long-term tests. On each graph, the measured temperature and pressure appear and for the graphs c), d) f) and j) corresponding to the lines 3, 4, 6, 10 respectively, the evolution of the pressure according to the temperature was added.

Table 9 : Long term tests results on the 10 lines tested in gas blend (40% H_2 + 60% CH_4)

Line number	Volume	P1	P2	T1	T2	ΔP corrected with the temperature	Duration of the test	Leakage rate
	l	*bar*	*bar*	*°C*	*°C*	*bar*	*h*	*l.h-1*
L1	**0,179**	1,0260	0,999	21,447	21,702	0,028	30	**1,66E-04**
L2	**1,15**	1,0342	1,00715	21,49	21,795	0,028	80	**4,03E-04**
L3	**3,324**	1,0358	1,0247	22,92	23,22	0,012	284	**1,41E-04**
L4	**0,461**	1,0358	1,0247	22,92	23,22	0,012	69	**8,06E-05**
L5	**10,576**	1,0335	1,03265	23,561	23,774	0,002	70	**2,37E-04**
L6	**8,237**	1,0349	1,02205	21,984	22,816	0,016	251	**5,14E-04**
L7	**0,221**	1,0372	1,03585	22,54	22,231	0,000	200	**2,94E-07**
L8	**0,744**	1,0360	1,00105	22,443	22,108	0,034	80	**3,14E-04**
L9	**0,355**	1,0355	1,0072	22,4	22,324	0,028	70	**1,42E-04**
L10	**0,422**	1,0355	1,0357	22,078	22,058	0,000	71	**-1,61E-06**

5 Discussion

The presented results are in agreement with the main conclusions of other projects on gas distribution network tightness [8] [4] [3]. The strong influence of the temperature on the pressure evolution was observed. For further investigations, specific apparatus measuring the temperature inside the pipeline to minimise the influence with ambient and weather conditions is recommended. Furthermore, the test should be carried out in a lab fitted with a well-controlled temperature.

The difficulty to obtain accurate results at low pressures was another conclusion from the Ukrainian consortium [7] and HyDelta project [8]. Indeed, in HyDelta the final leakage rate ratio between methane and hydrogen were extracted without taking into account the data generated at low pressure.

Generally, none of the leakage rates obtained on the short- and long-term tests were above the admissible leakage of the NEN 7244-7, and EN15502-1:2021 standards. Hence, once a gas line is properly installed, following NG standards, at low pressures (35 mbar) it can be expected that it will be tight in the gas blend.

On the long-term tests, no further increase of leakage rates were observed. Hence, for these test durations, no deterioration of the joints and coupling was induced by the gas blend. Furthermore, at these low pressures, the potential permeation of gas through the material can be neglected.

However, the consequences of a leakage of H_2 will **not** have the same consequences of a leakage with CH_4 or natural gas. A hydrogen leak will not necessarily be worse than a natural gas leak, as the ignition properties are depending on the dilution rate of the gas in the air and therefore consequences will also depend very much of the configuration of the room where there is a leakage (geometry, size, ventilation rate etc.).
Our conclusions are important for the authorities & organisations that will have to revise regulations and standard on leakages in light of our test results, but also in light of a risk assessment with H_2 leaks.

6 Conclusion

The present work evaluates the tightness of gas distribution components in the gas blend composed of (40% H_2 + 60% CH_4) through long- and short-term testing at a pressure of 35 mbar. The results, supported by other works, highlighted the strong influence of the temperature and the difficulty to obtain accurate results at low pressures.

From the results it can be concluded that in the tested conditions, and with gas lines properly installed, the leakage rates will be below the current admissible standard rates both for gas line and appliances as well. At those low pressures, no differences between leakage rates in air, He and in the H_2NG blend was observed. Furthermore, for the lines able to hold the pressure for longer, after about 200 hours of test, no deterioration of the components or loss of tightness was observed.

7 List of Illustrations

8 List of tables

9 References

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[5] S. Roberts and N. Ryan, ‘Hy4Heat WP7_Safety Assessment : Experimental Testing-Domestic Pipework Leakage’, Steer Energy Solution Ltd, Technical report TRN: 1819/02/2019 Lot 1, May 2020.
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[7] M. Karpash, P. Rayter, A. Yavorskyi, and A. Oliynyk, ‘Study of tightness of gas distribution networks in case of use for supply of gas-hydrogen mixtures’, Technical report, 2020.
[8] S. Lueb, ‘HyDelta WP1C Pipes and indoor installations (components)_D1C.2: Tightness of distribution pipes’, KIWA Technology B.V., Jan. 2022.
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10 Annexe 1

D5	meter connection + 2x pipe + 2x elbow + union	iron, brass	3/4"	
D6	2x pipe, 3x elbow (pressfittings) + 2x adapter to male thread, elbow	copper, iron	22 mm, 1/2", 3/4"	
D7	meter connection, valve, 2x elbow + pipe	iron, brass	1"	
D8A D8B	pipe + union filter + union	copper brass	3/4", 12mm 3/4"	 
D9	pipe + 2x elbow	iron	1"	
D10	meter connection, valve, 3x elbow + pipe	iron	1"	
D11	pipe + elbow	iron	1"	
D13	meter connection, reduction, 2x pipe, 3x elbow	iron, brass	3/4", 1/2"	
D14	meter connection, valve, 2x elbow, pipe	iron	1"	

D17	meter connection, valve, elbow	iron, brass	1", 3/4"	
D18	meter connection, 2x elbow, valve	iron	1"	
D15	meter connection + copper pipe	copper	3/4", 15 mm	
D19	meter connection, 3x elbow, pipe	iron	1"	 
D21	meter connection, valve, elbow	iron, brass	3/4"	
D22	meter connection, valve, 2x elbow	iron, brass	1"	

D24	meter connection, valve, 2x elbow, pipe	iron	3/4"	
D25	valve + elbow	iron, brass	3/4"	
D23	meter connection, elbow, valve	iron, brass	1"	
D26	pipe + elbow	iron	1"