NOVEL METHODS OF TESTING FOR MEASUREMENT OF NATURAL GAS AND HYDROGEN MIXTURES

D2.2

Methodology and test protocols (Testing protocols will be provided to WP3 as an input for testing)

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The THOTH2 project has received funding from the Clean Hydrogen Partnership under Grant Agreement No 101101540. This Partnership receives support from the European Union's Horizon Europe Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Co-funded by the European Union

Technical References

Project Acronym	THOTH2
Project Title	NOVEL METHODS OF TESTING FOR MEASUREMENT OF NATURAL GAS AND HYDROGEN MIXTURES
Type	Research and Innovation Action (RIA)
Call Identifier	HORIZON-JTI-CLEANH2-2022-05-04
Topic	Development of validated test methods and requirements for measuring devices intended for measuring NG/H2 mixtures
Project Coordinator	Matteo Robino (SNAM S.p.A.)
Project Duration	February 1, 2023 – July 31, 2025 (30 months)

Deliverable No.	D2.2
Dissemination Level	PU (Public)
Work Package	WP2 – Methodology and test protocols
Task	T2.2
Lead beneficiary	CESAME EXADEBIT SA
Contributing beneficiary(ies)	ENAGAS, FBK, GRTGAZ, GS, INIG, INRETE, INRIM, METAS, SNAM, UNIBO
Due date of deliverable	30/04/2024
Actual submission date	24/05/2024

Versions

Revision Version	Date	Changes	Changes made by Partner
0	02/05/24	First release	CESAME, Enagas, UNIBO, FBK, INIG, GAZ-SYSTEM, INRIM

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EXECUTIVE SUMMARY

This document presents the results of the research carried out in response to the questions posed by task 2.2 of WP2 of the THOTH2 project. In the following, we will present:

- Methodologies in order to investigate the aging on selected devices based on the assessment of the accuracy modification over a large period exposed to H2.
- Metrological protocol for lab comparisons with various devices under defined conditions.

These will be presented for different categories of devices, namely gas meters, pressure transmitters, water dew point analysers, flow computers and leak detectors.

Acronyms and Symbols

AISI	American Iron and Steel Institute
ATEX	ATmosphères EXplosibles
BS EN	British Standard European Norm
CH_4	Methane
CP	Common practice
DN	Nominal Diameter
DSO	Distribution System Operator
EN	European Norms
He	Helium
H2NG	Hydrogen added natural gas (hydrogen content in natural gas from 0 to 100%)
IEC	International Electrotechnical Commission
ILC	Interlaboratory Comparison
IR	Infrared
ISO	International Organization for Standardization
LFL	Lower Flammable Limit
LRV	Lower Range Value
P	Pressure
P_{min}	Minimum pressure
P_{max}	Maximum pressure
PN	Nominal Pressure
N_2	Nitrogen
NEC	National Electrical Code
Q_{min}	Minimum flow rate
Q_{max}	Maximum flow rate
RH	Relative Humidity
RP	Revised practice

SS	Stainless Steel
SoA	State of the Art
t	Time of response
TSO	Transmission System Operator
UFL	Upper Flammable Limit
UGLD	Ultrasonic Gas Leak Detectors
URL	Upper Range Value
UUT	Unit Under Test
Z	Compressibility factor
WP	Work Package

1. Measuring devices identified in WP1 and WP2 to be tested within WP3

In the frame of the THOTH2 project's Work Package 1 (WP1), one of the tasks was Task 1.1, in which a database of measuring devices was created. In the following, we will present those devices and the protocols that are written and planned to be used for testing them.

Statement: Gas Chromatographs (GC) have been discarded from the protocol definition (WP2) and testing (WP3) since the ones installed in the gas grid are not H2 ready (and won't be able to provide any relevant information on the H2 content). The next GC generation will be meant for hydrogen and blending but are not available within the project lifetime.

1.1. Gas meters

One of the aims of the THOTH2 project is to develop testing protocols and verification procedures for gas flow meters with pure H_2 or H2NG blends in order to evaluate their accuracy and durability, to determine the uncertainty and finally, to study and evaluate the integrity of the internal components of the meters, the durability of the materials, the behavior of the electronic components and other technical issues related to the presence of H_2. To this end, International Organization for Standardization ISO 17025-certified laboratories have come together as part of this project to carry out tests on different models of gas meters: ageing under H_2, calibration with different fluids such as air, NG, pure H_2 and H2NG blends, etc.

In what follows, we will introduce the meters on which the tests will be conducted, identify who will carry them out, define the duration of the tests, describe the testing resources available to the participating laboratories, and outline the requirements that must be met.

The first step of this work was to identify the different types of meters currently installed in the natural gas distribution or transport networks. These meters must comply with standards such as ISO 15970, ISO17089, and European Norms (EN) including EN 1359, EN 14236, EN 17526, EN 12405-1, EN 12480, and EN 12261. Additionally, these meters must meet the conditions for use in an ATmosphères EXplosibles (ATEX) environment (at least rated IIA (for NG), IIC (for H_2 or H_2 blendings) being preferred).

A selection was made according to the network and the following criteria:

Transmission System Operator (TSO)

- Rotary meters
- Turbine meters
- Ultrasonic meters

Distribution System Operator (DSO)

- Ultrasonic meters
- Diaphragm
- Thermal mass meters

Based on criteria such as the rate of model type used on current natural gas networks, the following meters have been selected. The table below, Table 1 shows the meters that are installed in the DSO gas grid, including their nominal diameter (DN) and nominal pressure (PN).

Table 1. DSO gas meters

NB	DSO	
	USM	**Calibre / DN / PN**
1	Sagemcom/Siconia (ES4EVO)	G4
2	Sagemcom/Siconia (ES4EVO)	G6
3	Flonidan (SciFlo®)	G4
4	Flonidan (SciFlo®)	G6
	Diaphragm	**Calibre / DN / PN**
5	Sagemcom (EG4)	G4 (T conversion)
6	Sagemcom (EG4)	G6 (T conversion)
7	Sagemcom/Siconia /Sacofgas (EG)	G10 (PT conversion)
8	Sagemcom/Siconia /Sacofgas (EG)	G16 (PT conversion)
9	Elster/Honeywell (BK)	G40
10	Elster/Honeywell (BK)	G65
	Thermal Mass	**Calibre / DN / PN**
11	Metersit (Domusnext)	G6
12	Metersit (Domusnext)	G25

Table 2 below shows the meters that are installed in the TSO gas grid or in both (DSO/TSO):

Table 2. TSO gas meters

NB	TSO	
	USM	**Calibre / DN / PN**
1	SICK FLOWSIC600	DN100
2	SICK FLOWSIC500	DN300
3	KHRONE ALTOSONIC V12	DN300
4	KHRONE ALTOSONIC V12	DN100
5	Honeywell Q. SONIC-4	DN300
	Rotary piston	**Calibre / DN / PN**
6	ITRON Delta S1	G100
7	ITRON Delta S3	G250
8	COMMON CGR-01	G100
9	COMMON CGR-01	G250

	Turbine	Calibre / DN / PN
10	ELSTER SMRI	G160
11	ELSTER SMRI	G650
12	ITRON FLUXI	G160
13	ITRON FLUXI	G650

These selected meters will be tested for the duration of the ageing and calibration campaign on the test benches of the partners who have been selected in the deliverable D3.1 which is summarized in the following paragraph.

According to the results of the previous work in D3.1, the test facilities available or under construction by the various partners that will be used are shown in Table 3 below:

Table 3. Summary of partners' capabilities

Summary of the characteristics of tyhe existing facilities already available for gas meter testing						
	CESAME	ENAGAS (*)	GRTGAZ	GS	INIG	METAS
Fluid	Air + gases (*) H2	Hydrogen Natural gas blendings only (H2NG) Air	+ gases (*)	Natural gas	Air, Natural gas H2 and H2NG	H2
Size of meter that can be tested	up G650 at patm	Up to G400 Natural gas Air	Up to G160	up to G2500	up to G65	up to G40
Flowrate range (Nm3/h) or (kg/h)	[5;50000] 0.3 - 20 kg/h	-	[0.1;2000]		[0.016;130]	
Flowrate range (actual conditions) (m3/h)	-	[3;650] 10 to 10.000 m3/h 5 to 10.000 m3/h	-	[8;4000]	-	[0.01;50] [0.01;150]
Operative pressure range (barg)	[1, 40] [1; 50] [0; 35]	[1,90] 3 to 50 barg (accredited range 16 to 50 barg) Atmospheric	30	[8,54]	0.1	[1,50]
Maximum allowable H2 content, [%]	0 Up to pure H2	100%	100%	0	100%	only 100%
Nominal DN range	[DN25; DN400] [DN15; DN50]	[DN50; DN150] 2 to 24 inches (DN50 to DN600) 2 to 24 inches (DN50 to DN600)	DN80 (up to 3")	DN50-DN400	DN50	MISSED

Based on the information provided by the various partners regarding the availability of their test facilities in the coming months and their ability to participate in the upcoming work, we have distributed the workload among the partners. This distribution is detailed in

Table 4 (for TSO gas meters) and Table 5 (for DSO/TSO gas meters):

Table 4. Workload distribution for TSO/DSO gas meters

Rotary	ITRON Delta S1	G100	CESAME/Air	CESAME/Air	CESAME/Air	25 vol-% H2 CESAME
		G250	DNV/CESAME/GRTgaz/ENAGAS/GS	DNV/CESAME/GRTgaz/ENAGAS/GS	DNV/CESAME/GRTgaz/ENAGAS/GS	100% H2 GRTgaz
	COMMON CGR-01	G100	CESAME/Air	CESAME/Air	CESAME/Air	25 vol-% H2 CESAME
		G250	GS	--	GS	100% H2 GRTgaz
Turbine	ELSTER SM-RI	G160	DNV/CESAME	DNV/CESAME	DNV/CESAME	100% H2 GRTgaz
		G650	GS	GS	GS	25 vol-% H2 CESAME
	ITRON FLUXI	G160	DNV/CESAME	--	DNV/CESAME	100% H2 GRTgaz
		G650	DNV/CESAME/GRTgaz/ENAGAS/GS	DNV/CESAME/GRTgaz/ENAGAS/GS	DNV/CESAME/GRTgaz/ENAGAS/GS	25 vol-% H2 CESAME
Ultrasonic	SICK FLOWSICK 600	DN100	DNV/GRTgaz	GRTgaz	DNV/GRTgaz	100% H2 GRTgaz
		DN300	ENAGAS	ENAGAS	ENAGAS	25 vol-% H2 CESAME
	KROHNE ALTOSONIC V12	DN100	DNV/GRTgaz	GRTgaz	DNV/GRTgaz	100% H2 GRTgaz
		DN300	ENAGAS	ENAGAS	ENAGAS	25 vol-% H2 CESAME
	HONEYWELL Q.SONIC-4	DN300	ENAGAS	ENAGAS	ENAGAS	25% H2 CESAME

Table 5. Workload distribution for DSO gas meters

Type	Model	Size	Calibration			Ageing
			Initial	Intermediate	Final	
USM	Sagemcom/Siconia (ES4EVO)	G4	GRTgaz (NG)	GRTgaz (NG)	GRTgaz (NG)	25 vol-% H2 INIG
		G6	GRTgaz (NG)	GRTgaz (NG)	GRTgaz (NG)	100% H2 INIG
	Flonidan (SciFlo®)	G4	GRTgaz (NG)	GRTgaz (NG)	GRTgaz (NG)	25 vol-% H2 INIG
		G6	GRTgaz (NG)	GRTgaz (NG)	GRTgaz (NG)	100% H2 INIG
Diaphragm	Sagemcom (EG4)	G4	METAS (100%H2)	METAS (100%H2)	METAS (100%H2)	25 vol-% H2 INIG
		G6	METAS (100%H2)	METAS (100%H2)	METAS (100%H2)	100% H2 INIG
	Sagemcom/Siconia /Sacofgas (EG	G10	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	25 vol-% H2 INIG
		G16	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	100% H2 INIG
	Elster/Honeywell (BK)	G40	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	25 vol-% H2 INIG
		G65	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	100% H2 INIG
Thermal Mass	Metersit (Domusnext)	G6	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	25 vol-% H2 INIG
	Metersit (Domusnext)	G25	INIG (25% H2)	INIG (25% H2)	INIG (25% H2)	25 vol-% H2 INIG

Procedure for exchanging meters between partners

As the workload distribution shows, partners will have to exchange the meters between them. To do so, a procedure of that exchange is written:

- **For sending meters to another partner, the partner should:**
    - Take photos of each meter.
    - Pack the meters and any other associated equipment securely.
    - Take photos of the package.
    - Create labels mentioning the set.
    - Shipping the meter.
    - Informing by e-mail the partner to whom the meters have been sent.
    - Include the photos that are taken in the information email.

- **On receipt of the meters**
    - Take photos of the package
    - Unpacking the meters
    - Take photos of each meter
    - Observe any damage that may have occurred during delivery.

- Inform the partner that has sent the meters.
- If there is any damage, include its photos into the e-mail.
- Store the meters until the date on which the tests take place.

This procedure is repeated before the start of the tests and at the end of each ageing phase to give rise to the calibrations.

1.2. Pressure transmitters and temperature transmitters

Accordingly with the deliverable D1.1, several different types of pressure transmitters were identified in the THOTH2 gas grids, including capacitive, piezoresistive and resonant types. Since it would not be possible to test all the models identified with the available resources, it was decided to limit the application of the developed protocol to the most relevant ones in terms of installed number.

The selection of the configuration to be tested is a decisive step in the experimental activity and it is discussed in deliverable D2.1.

Focusing on materials of the diaphragm, the literature indicates the following performances of the typical materials used in pressure transmitters when in contact with H2 (Table 6).

Table 6. General overview of material performances when in contact with H2.

Material	General overview
Tantalum	Tantalum can suffer severe embrittlement if in service with high-temperature oxygen or nitrogen, or with hydrogen at any temperature. Also, it is attacked by strong alkaline solutions and by fused alkalis like sodium hydroxide embrittlement than most other metals
Monel	When used as a diaphragm material, hydrogen atoms may permeate the diaphragm allowing hydrogen bubbles to form within the fill fluid. Therefore, Monel should not be used as a diaphragm material when the process contains hydrogen
Hastelloy	Hastelloy C, like Monel and AISI 316L stainless steel, allows hydrogen to permeate diaphragms therefore should be avoided as a diaphragm material for use in hydrogen service
Gold plated	High resistance to hydrogen permeation
316 SST	Type 316 SST performs very well against hydrogen diffusion and is a good choice as a diaphragm material when the process is hydrogen gas
Alloy C-276	C-276 can be susceptible to hydrogen permeation and is thus not the best fit for hydrogen rich applications
Alloy 400	One challenge with Alloy-400 material is that it is more susceptible to hydrogen permeation. Therefore, Alloy-400 should not be used as a diaphragm material when the process is hydrogen gas or when hydrogen atoms are present unless other protection mechanisms

That is, the THOTH2 industrial partners were asked to define the main characteristics of the measuring device under test. Moreover, the manufacturers will be asked to specify the materials of those components in contact with the gas mixture such as those configurations parameters of their products that could be affected by the presence of H2.

When more than one choice is possible, THOTH2 partners will decide. Those configurations representative of the currently installed devices in the networks will be preferred.

Once the configuration is confirmed, the instrument documentation of the pressure transmitters will be asked to the manufacturers preferably, and when possible, in accordance with Annex B of the ISO 15970.

Based on the mentioned considerations, six different devices have been selected to validate the developed protocols in agreement with THOTH2 consortium, see Table 7 below:

Table 7. Pressure transmitters selected for the validation of the testing protocol.

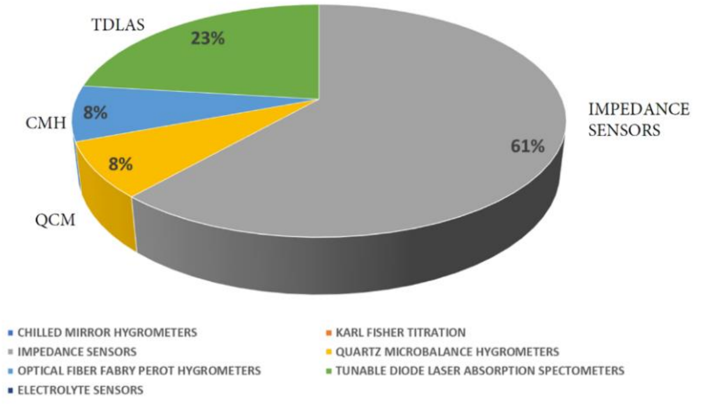
N	Sensor Model
1	YOKOGAWA EJA 310 E
2	ROSEMOUNT 3051 C
3	APLISENS APC 2000
4	ROSEMOUNT 3051 T
5	YOKOGAWA EJA 430 E
6	YOKOGAWA EJA 310 A

Despite in the project proposal, the partners indicated the definition of protocols for temperature transmitters, after an extensive discussion among partners, it was agreed to not proceed in testing due to technical reasons. In fact, the temperature transmitter's sensor is usually installed in thermowell. Therefore, the sensor is not in contact with the medium to be measured. Therefore, no change in the metrological performances is expected in case of NG, H2NG or pure H2 but only potential impact on the material of the thermowell, i.e., excluded by the scope of the THOTH2 project.

1.3. Water dewpoint analysers

Following Deliverable D1.1 results, different types of water dew point sensors and analysers were identified in the THOTH2 gas grids, including spectroscopic analysers, QCMs, metal oxides sensors and CMH. Figure 1 provides an overview of the water dew point sensors and analysers used by TSO and DSO in their facilities.

Figure 1. Measuring technology implemented in the gas grid for water dew-point measurement.



Since not all identified models are available for testing and, in any case, it would not be possible to test all the models, it was decided to limit the testing and calibration to the most relevant ones.

Table 8. shows the water dew point analysers used by TSO and DSO in their plants or laboratories. A few of these analysers, as outlined in Table 9, has been selected for testing, as described in Section 5.3.

Table 8. List of water dew point analysers.

Manufacturer	Model	Technology
MICHELL	CONDUMAX II	Impedance sensor (Water dew point)
MICHELL	Easidew PRO IS	Impedance sensor
AMETEK	OLV 3050	Quartz-Crystal microbalance
BARTEC	L1660	Fiber optic
GE INDUSTRIAL - PANAMETRICS	MIS-2	Impedance sensor
GE INDUSTRIAL - PANAMETRICS	MMS3	Impedance sensor
GE INDUSTRIAL - PANAMETRICS	AURORA	TDLAS
HONEYWELL	4112	Impedance sensor
MICHELL	TDL600	TDLAS
MICHELL	PROMET EExd	Impedance sensor
MICHELL	Transmet I.S.	Impedance sensor
MICHELL	SF-52	Impedance sensor
STORK INSTRUMENTS	DEWCom II Transmitter	Impedance sensor
ALPHA MOISTURE SYSTEM	SADPmini2-Ex	Impedance sensor
ALPHA MOISTURE SYSTEM	AMT-Ex	Impedance sensor
ALPHA MOISTURE SYSTEM	SADPmini-Ex	Impedance sensor
ALPHA MOISTURE SYSTEM	ADHT-Ex	Impedance sensor
ALPHA MOISTURE SYSTEM	DSP-Ex	Impedance sensor
ALPHA MOISTURE SYSTEM	SADPμ	Impedance sensor
BAKER HUGHES	Aurora	TDLAS Moisture Analyzers
BAKER HUGHES	HygroProII	Impedance sensor

Table 9. Water Dew Point Analysers selected for testing.

N	Sensor Model	Technology	Sensor Owner
1	Endress+Hauser J22	TDLAS	SNAM
3	Michell PROMET EExd	Ceramic Metal-Oxide Moisture Sensor	GAZ-SYSTEM
5	Michell TDL 600	TDLAS	SNAM
6	Michell Transmet I.S.	Ceramic Moisture Sensor	GAZ-SYSTEM
7	SHAW SDT-Ex	Aluminum oxide technology sensors	INRIM
8	Michell Easidew PRO XP	Aluminum oxide technology sensors	INRIM

1.4. Flow computers

Around 100 different models of flow computers are installed in gas grids of TSO participating in the project. Nevertheless, just two equations of state are currently implemented in these devices for compressibility factor calculation:

- AGA8 / EN ISO 12213-2 [1].
- SGERG88 / EN ISO 12213-3 [2].

Therefore, the testing protocol focuses on the evaluation of these compressibility factor calculation methods. For estimating the error of tested methods, the results will be compared with the values obtained with other reference method.

Additionally, a flow computer will be tested to analyze its performance for different hydrogen concentrations (inside and outside of limits defined in standards).

1.5. Leak detectors

During the SoA analysis performed in D1.1, it was highlighted that TSOs and DSOs use several different types of leak detectors for monitoring NG leakages in their plants and laboratories. Table 10 summarizes the list of the most used devices by TSOs and DSOs. These devices have been selected for testing in WP3 for investigating the impact of the presence of H2 in the NG/H2 blends on their detection performance.

Table 10. Leak detectors selected for testing.

Manufacturer	Model	Technology
MSA Safety Incorporated	Altair 4	Catalytic sensor
MSA Safety Incorporated	Altair 5	IR + Catalytic sensor
Dräger	XAM 5000 4G	Catalytic + electrochemical sensors
Gazomat	INSPECTRA LASER	Infrared sensor

Teledyne Gas Measurement Instruments	GT series 40	Semiconductor CH4 0-100% LEL, 1% Catalytic Bead, CH4 0-100% Volume, 1% Thermal Conductivity
Teledyne Gas Measurement Instruments	PS200	Catalytic sensor
Huber Günther & C.	Protheo IR compact	Infrared sensor
Huber Günther & C.	METREX 2	Semiconductor + catalytic + thermal conductivity sensors
SENSIT	HXG-3P	Semiconductor + catalytic + thermal conductivity sensors
SENSIT	LZ-30	Infrared sensor

Additionally, ultrasonic gas leak detectors (MSA Safety Observer® and Distran Ultrapro®) could be added to the list as representative devices to be tested for evaluating the performance of acoustic based sensors in the presence of H2NG blends. Only H_2 influence on device limit of detection will be evaluated.

This tentative list of sensors to be tested in WP3, according to the test protocol outlined in this document, includes both fixed and transportable/portable devices. The list of sensors may be modified based on the input and preferences of the THOTH2 advisory board members. In addition, changes to the list could be considered based on manufacturers' suggestions, e.g. the presence on the market of one of their sensors that is best suited for H2NG leakage detection and that they intend to propose to the TSO/DSO as a replacement for the sensors currently used for pure NG leakage detection.

2. Testing protocols

2.1. Testing protocols for pressure transmitters

2.1.1. Terms and definitions used

The following terms and definitions apply. Where applicable, the terms are defined in accordance with the relevant standards (e.g., ISO 15970, EN 61298)

- *Ageing*: the process of maintaining the measuring device at specific operative conditions for a specific period of time in order to evaluate the effects due to the exposure with H2 molecules.
- *Calibration*: the comparison of measurement of the measuring device under test with those of a calibration standard of known accuracy.
- *Class*: class of measuring instruments or measuring systems that meet stated metrological requirements that are intended to keep measurement errors and instrumental uncertainties within specified limits under specified operating condition. In the case of pressure gauge, the class defines the permissible deviation of the display in percent of the full-scale value.

- *Pressure transmitter*: device that responds to a measured pressure to produce a standard output signal for transmission, which has a prescribed continuous relationship to the value of the measured pressure.
- *Upper Range Value (URL)*: highest value of the pressure that a transmitter is adjusted to measure.
- *Purging*: the operation to remove any trace of air or other gases from the system with an inert gas like, for example, nitrogen.
- *Range*: range of values defined by the two extreme values within which a variable can be measured within the specified accuracy
- *Set point*: the desired value of pressure to be maintained.

2.1.2. Motivations

The experimental testing of the pressure transmitters will consist of two consecutive phases, i.e., the ageing and the calibration. In fact, it is known that, due to its size, H2 molecule can penetrate through diaphragm material affecting the metrological performances.

Since no real H2 or H2NG grids would be available to perform the test in the field, it was decided to perform ageing in laboratory for two consecutive periods of time assumed equal to 4 months each.

Between the two ageing periods:

The effect of H2 ageing will be finally verified through periodic calibration, i.e., at the beginning, between the two ageing periods, and at the end.

In the following sections, the developed protocol for ageing and calibration is indicated.

2.1.3. Ageing of the pressure transmitters

Test duration

The duration of the test shall be sufficient to assess long-term drift behaviour and at least, not less than those indicated in ISO 61298.

Gas composition during test

The gas composition shall be the same of the expected fluid conditions.

The gas composition shall be maintained during the entire duration of the ageing.

For the purpose of the testing activities in the THOTH2 project, two levels have been agreed by the partners, i.e., 100%vol. H2 (i.e., pure H2), and H2NG mixture with a content of 25%vol of H2 in NG.

The composition of the gas to be used during ageing shall be documented. In the case of pure H2, at least 4.0 purity H2 (99.99%) shall be used. In case of H2NG mixture, a H2 and CH4 mixture shall be used rather than H2 and NG mixtures. Using CH4 compared to NG would ensure the reproducibility of the results avoiding other effects due to other components in the NG.

Proper documentation must be available to declare the composition of the testing gas.

Gas pressure during test

The gas testing pressure shall be the representative of the expected range in the field.

The gas testing pressure must be maintained within ±2.5% of the Upper Range Value (URV) for the entire duration of the test. For this purpose, testing pressure shall be controlled by at least a Class 0.6 manometer or by other devices ensuring an equivalent metrological performance. Whenever possible, electronic pressure devices with a recording function should be preferred. The range of the pressure indicator or the pressure transmitter shall be selected properly in accordance with the ageing pressure.

In the case of automatic monitoring, pressure should be controlled at least at the rate of one time per hour.

The model, manufacturer and the configuration details of the pressure measuring devices used must be specified in the ageing report.

A gas pressure reducing regulator settled at the testing pressure shall be used to supply the testing bench. Preferably a two-stage pressure regulator should be adopted. For better resolution and control, the pressure control range should preferably closely match the testing pressure.

The model, the manufacturer and the selection configuration of the pressure reducing device shall be indicated in the ageing report.

Gas temperature during test

Since the test is performed in static mode, gas temperature is assumed to be equal to ambient temperature. However, ageing should be preferably performed in indoor environment where temperature can be controlled between among ± 5° C of the desired set point.

The model, the manufacturer and the selection configuration of the temperature measuring devices used (if any) shall be indicated in the ageing report.

Identification and inspection of the device before ageing

At the laboratory, the instruments shall be stored under suitable ambient conditions, and in their packing, and shall be taken out and commissioned just before the start of the programme of tests.

A visual inspection of the device and of the packing should be made for damage sustained during transit. In the case of visible damages to the device, the test has to be immediately interrupted.

Installation of the measuring devices

The pressure transmitters shall be prepared and mounted in accordance with the instruction manual provided by the manufacturer. During each test, no adjustment shall be made.

If more than one device is tested simultaneously, connecting manifold could be used.

In the case that the tested devices are connected to a common manifold, the system should be designed in order to allow the safe removal of each single devices without affecting the others in case of malfunctions or any other unexpected events. For this purpose, block and bleed valves should be preferably used on each device.

Shuttle valves shall be installed upstream and downstream the test bench.

To minimize the risk of accident, flashback arrestors should be installed upstream and downstream the test bench to avoid flame propagation or air return into the system.

Preconditioning of the devices under test

Purging with inert gases shall be performed to remove any trace of air before ageing. Purging shall be continued until gas composition measured downstream the device/s to be tested will not affect the testing results and will not pose any risk to the testing operator/s. For this purpose, a gas chromatograph can be used.

The duration of the purging shall be carefully assessed by the testing operator. Purging fluid shall be an inert gas, preferably nitrogen or helium. Purging pressure shall be higher than ambient pressure and lower of the ageing testing pressure to not damage the device. Purging pressure, fluid and duration shall be declared in the ageing report. Once purging is completed, air shall not be allowed to enter again in contact with the device to be tested.

Flushing with the gas to be used for testing shall be performed after the purging phase and before starting the ageing. Flushing shall be continued until gas composition measured downstream the device/s to be tested is the one declared for testing for at least 60 sec. For this purpose, a gas chromatograph can be used. Other type of rules to define the duration of the flushing shall be technically justified.

Proper technical solutions to safely handle gas flushing downstream the devices under test have to be identified before starting the testing.

Flushing pressure shall be higher than ambient pressure and lower of the ageing testing pressure to not damage the device.

Flushing pressure, fluid and duration shall be declared in the ageing report.

For purging and flushing phases, dedicated gas pressure reducing regulator settled at the set point pressure shall be installed upstream the device/s. Preferably a two-stage pressure regulator should be adopted. For better resolution and control, the pressure control range should preferably closely match the set pressure.

The pressure reducing regulator used for flushing could be also used for the supply of the ageing testing gas. In this case the pressure control range shall match the ageing testing pressure.

The model, the manufacturer and the selection configuration of the pressure reducing devices used shall be indicated in the ageing report.

End of ageing operations

Once the ageing is completed, the gas mixture shall be safely disposed outside the device. Proper technical solutions to safely handle the disposal of the gas mixture shall be identified before starting the testing in order to avoid the presence of hazardous mixtures between air and flammable/explosive gases.

Gas purging shall be started once the ageing testing pressure have been discharged.

Purging with inert gases shall be performed to remove any trace of testing gas. Purging shall be continued until gas composition measured downstream the device/s to be tested contain trace of testing gases in the mixture. For this purpose, a gas chromatograph can be used. Other type of rules to select the duration of the purging shall be technically justified.

The purging gas stream shall be safely vented. Purging fluid shall be an inert gas, preferably nitrogen or helium. Purging pressure, fluid and duration shall be declared in the ageing report. Once purging is completed, air shall not be allowed to enter again in contact with the device to be tested.

2.1.4. Calibration of pressure transmitters

Since the calibration of pressure transmitters is well known in the literature, no need appears in the definition of new protocols.

The EN 61298 series "*Process measurement and control devices - General methods and procedures for evaluating performance*" can be considered as an accepted alternative to the protocol defined below.

Choice of reference measuring equipment

The measurement instruments have been selected so as to permit correct measurement (in terms of accuracy and reliability) of the performance of the devices to be tested.

The uncertainty of the measuring equipment shall be not greater than 1/4 of the stated limit of error for the device being tested. The value has to be reported in the final test report.

The traceability of the measuring equipment shall be ensured. For this purpose, the reference measuring equipment shall be periodically calibrated and certified against instruments or procedures traceable to the appropriate national standard.

Identification and inspection of the device before calibration

At the laboratory, the instruments shall be stored under suitable ambient conditions, and in their packing, and shall be taken out and commissioned just before the start of the programme of tests.

A visual inspection of the device and of the packing should be made for damage sustained during transit. In the case of visible damages to the device, the test has to be immediately interrupted.

Preconditioning: ambient and device under test stabilization

Testing ambient conditions (i.e., temperature, relative humidity) shall be stabilized before starting the calibration procedure.

Environmental test conditions should be maintained as reported in Table 11. Furthermore, the maximum rate of change of ambient temperature permissible during any test shall be 1 C in 10 min, but not more than 3 C/h.

Table 11: Environmental test conditions

Atmospheric test conditions	Temperature [C]	Relative humidity [%]	Atmospheric pressure kPa
Standard reference atmosphere	20	65	101.3
Recommended limits	15-25	45-75	86-106

Once ambient testing conditions are stabilized, a sufficient time shall be allowed to also ensure the stabilization of the operating temperature of the reference device and of the device under test. Specifically, with power applied to the device under test, a sufficient time shall be allowed to ensure stabilization of the operating temperature. The stabilization shall not be shorter than 30 min.

Installation of the device under test

Once the temperature is stabilized, the device under test shall be installed to the test bench. The instruments shall be installed in accordance with the manufacturer's instructions. Regarding vibration, the installation of the device shall be such as to avoid any effect due to vibrations induced from outside the device during the tests. The electric supply shall be compliant with those indicated by the manufacturers in the manual of the devices.

Calibration of the device: testing gas

Inert gas like nitrogen shall be used for calibration.

Calibration of the device: testing points under test

The performance of the device under test shall be verified over the full range for increasing and decreasing values. The number of measurement cycles and of test points shall be in accordance with those indicated in Table 12.

Table 12. Number of measurement cycle and test points

P_{MIN}	P_2	P_3	P_4	P_{MAX}
⇨1	2	3	4	⇩5
10	9	8	7	⇦ 6

where:

$$P_2 = \frac{3P_{min} + P_{max}}{4}$$

$$P_3 = \frac{P_{min} + P_{max}}{2}$$

$$P_4 = \frac{3P_{max} + P_{min}}{4}$$

For each measurement point, five measurements of the reference pressure and five measurements of the transducer output value should be performed.

Anomalies and failures during tests

If during the tests (ageing or calibration), any unexpected event, anomalous performance, or failure of the device under test occurs, the test has to be interrupted. In this case the event shall be recorded in the test report, together with any related cause, and the actions taken.

When a test has been interrupted during calibration, the possibility to continue the test or to re-start it should be considered based on the test criteria, the failure or the anomaly that occurred. In the case of re-start of the evaluation after repairing a failure, it is advisable to repeat the measurements from the beginning, because before turning into a failure, a developing fault might have influenced the previous measurements performed so far.

In the case it was identified that improper handling of the device under test caused the anomaly or the failure during the test, the previous results shall not be reported.

2.2. Test protocols and procedures for gas meters

2.2.1. Ageing

The selected meters will be pressurised with 100% H2 or a CH4/H2 mixture with 25% H2.

Conditions and configuration

ATEX area

The room housing the ageing meters will be considered as an ATEX zone, so the following points must be complied with:

- Be able to automatically isolate cylinders from their ageing line in the event of gas detection, overpressure, or low pressure.
- In case of isolation, the maximum quantities of gas present in each line must be able to be evacuated by the ventilation system in a very short time.
- Meters undergoing ageing tests should therefore be housed in an area where the air is renewed by means of a ventilation system designed for this purpose.
- Electrical equipment in contact with gas within this volume must be ATEX compliant.

Ageing mode

These ageing tests will be carried out by the various partner laboratories with ageing test benches. They will be carried out in static or dynamic mode.

Pressure and temperature conditions

In terms of pressure, the meter will be subjected to a pressure equal to its nominal pressure + or - 15% (PN+or-15%PN).
As for temperature, in static mode it is equal to the ambient temperature of the room in which testing takes place. In dynamic mode, this temperature must be brought up to the room's ambient temperature.

The configuration will depend on the capabilities of the partner laboratory. It would be ideal to be able to age several meters at the same time.

Data acquisition and recording

An acquisition unit will continuously record the signals from the various sensors, at the rate of one acquisition per hour.

- The pressure at the meters is recorded to ensure that they are kept under pressure throughout the tests.
- For the test room: 3 ambient condition sensors (Pressure, Temperature, Hygrometry) as well as one or more H2 detectors in the volume.

Gas mixture to be used for ageing

It has been decided that some partners will carry out the tests with 100% H2 and others with H2 blends (CH4: 75% + H2: 25%).

The workload distribution tables (

Table 4 & Table 5) show which fluid is to be used by each partner responsible for the tests.

Duration

The gas meters are classified by set according to their calibre, and ageing will be carried out in different phases: firstly, an initial phase lasting 11 months, then a second phase lasting 5 months for some sets, and a single phase lasting 16 months for others.

The Table 13 below summarises the duration for TSO gas meters by each set of meters and the laboratory that's responsible for its ageing:

Table 13. TSO/DSO gas meters testing duration

Sets	Meters	Calibre /DN/PN	Lab for ageing	Ageing 1 duration	Ageing 2 duration
Set 1	SICK FLOWSIC 600, KHRONE ALTOSONIC V12	DN100	GRTGAZ	11	5
Set 2	SICK FLOWSIC 600, KHRONE ALTOSONIC V12	DN300	CESAME	11	5
Set 3	Honeywell Q.SONIC-4	DN300	CESAME	11	5
Set 4	ITRON DELTA S1, COMMON CGR-01	G100	GRTGAZ	11	5
Set 5*	ITRON DELTA S1, COMMON CGR-01	G250	GRTGAZ	16	
Set 6	ELSTER SMRI, ITRON FLUXI	G160	CESAME	126	
Set 7	ELSTER SMRI, ITRON FLUXI	G650	CESAME	11	5

For DSO gas meters, they have also been classified in different sets and duration has been decided for each one as in the Table 14 below:

Table 14. DSO gas meters testing duration

Sets	Meters	Calibre /DN/PN	Lab for ageing	Ageing 1 duration	Ageing 2 duration
Set 1	Sagemcom/Siconia (ES4VO) Flonidan (Sciflo)	G4 and G6	INIG	11	5
Set 2	Sagemcom (EG4)	G4/G6	INIG	11	5
Set 3	(**) Sagemcom/Siconia /Sacofgas (EG) Elster/Honeywell (BK)	G10/G16/G40/G65	INIG	11	5
Set 4	Metersit (Domusnext)	G4/G6/G25	INIG	16	

2.2.2. Calibrations

At the end of each phase of ageing, calibrations of the meters either with air, NG, H2 or H2 blends by different partners take place. The test equipment used for this purpose consists of a reference flow measurement system equipped with the necessary measuring equipment (fluid pressure and temperature) and a test section placed in series on which the meter is mounted.

The test method is a comparison method, which involves determining the difference between the meter flow rate and the reference flow rate.

The traceability of these means is confirmed, and the uncertainties will be communicated in the results file.

Conditions and configuration

Test lines set up

To calibrate the meters, the configuration requires certain conditions to be met on various elements of the circuit. The following are the requirements that need to be met to carry out the tests in the best possible conditions.

Straight lengths

The minimum straight lengths of sleeves of the same nominal diameter placed upstream and downstream of the meters are as follows:

- Upstream > or = 10 D

- Downstream > or = 5 D

Nominal diameters

The nominal diameters of the meter flanges must be compatible with the mounting line, and the number of bolts installed must be compatible with the test pressure.

Pressure tapping

The pressure tap must be on the meter and must be identified.
For rotary piston meters, if there is no device creating a loss of mass energy upstream of the meter, it is permitted to use a pressure tap located at approximately 1 D to 3 D from the meter flange.

Temperature tapping

For all types of meters, the temperature is taken on the downstream pipe at a distance close to the meter (around 3 D).

Reference ambient temperature

Temperature difference between ambient air and calibration media inside the meter must allow to minimise the thermal exchange and to facilitate laboratories CMC according to its uncertainty budget.

As far as pressure is concerned, meters will be calibrated at only one pressure point.
The following Table 15 summarises the pressure and flow points at which we will calibrate the meters:

Table 15. Test matrix for gas meters [1], [2], [3]

Gas meter calibration					
Pressure (Barg)					
16					
Flowrates					
Qmin	0.05Qmax	0.2Qmax	0.4Qmax	0.7Qmax	Qmax

The calibration at each flow point should be repeated at least 3 times and the final value taken will be the average point.

Gas mixture to be used for gas meters' calibrations

Gas meters will also be calibrated with different gases, including air, NG, CH4/H2 mixtures (25 or 100% H2) or any other fluid, depending on the requirements and capacity of each partner.

Results of the calibrations

The results will be gathered by task lead and be shared after having been treated with the different partners for validation.

Each laboratory that will be involved in the calibrations should send the following Table 16 to the WP2 leader.

Table 16. Results to be sent to the WP2 leader.

Characteristics		Results			
Set number		Date			
Meter number		Calibration pressure			
Owner		Fluid			
Type					
Model		Flowrate (m3/h)	Points (Qmin or in % Qmax)	Reynolds number	Shift (%)
Calibre			Qmin		
Year			5		
Manufacturer			20		
Nominal diameter			40		
Nominal pressure			70		
Qmax			100		
Qmin					
Qt		Uncertainty		%	
Totalizer					
LF value		Done in		Lab name	
HF value		Validation		OK/NOK	

The WP2 leader will present the results represented for each meter when it's calibrated at the end of each ageing phase in order to show the gap that might occur because of the presence of H2. See on appendix the final report of results for each meter.

Planning

During the test campaign, an initial calibration will be carried out on the meters to identify their metrological status, which will serve as a reference for the rest of the campaign. This initial calibration will be followed by an ageing phase until the last calibration for certain meters. For others, after this initial ageing phase, a second calibration will be carried out, followed by a final ageing phase and a final calibration. This planning is summarized in the Table 17 and the Table 19 below:

		Fluid	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18
DNV*, GRT GAZ	set 1	100%H2, 25%H2, NG	A1,A2,D1,D2	100% H2 : GRT GAZ											A3,A4	100% H2 : GRT GAZ					A5,A6,D3,D4
ENAGAS	set 2	NG	B1,B2	25% H2 : CESAME											B3,B4	25% H2 :CESAME					B5,B6
CESAME	set 4	AIR	C1,C2	25% H2 : CESAME											C3,C4	25% H2 : CESAME					C5,C6
DNV, CESAME,GRT GAZ, ENAGAS, GAS SYSTEM	set 5*	100%H2, 25%H2, NG, AIR	D5,D6,D7,D8,C7,C8,A7,A8,B7,B8,E1,E2	100% H2 : GRT GAZ																	D9,D10,D11,D12,C9,C10,A9,A10,B9,B10,E3,E4
DNV, CESAME	set 6	100%H2, 25%H2, AIR	D13,D14,D15,D16,C11,C12	100% H2 : GRT GAZ																	D17,D18,D19,D20,C13,C14
GAS SYSTEM	set 7	NG	E5,E6	25% H2 : CESAME											E7,E8	25% H2 :CESAME					E9,E10
INIG																					
METAS																					

Table 17. Planning for TSO meters

		Fluid	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18
GRTGAZ, INIG	set 1	NG	All the meters of the set by GRT	100% H2 for 1 G4 and 25% H2 for 1 G6 of each model : INIG											all the meters of the set by GRT	100% H2 for 1 G4 and 25% H2 for 1 G6 of each model : INIG					all the meters of the set by METAS
METAS, INIG	set 2	100% H2	all the meters of the set by METAS	25% H2 G4 and 100% H2 G6 : INIG											all the meters of the set by METAS	25% H2 G4 and 100% H2 G6 : INIG					all the meters of the set by METAS
INIG	set 3	25% H2	all the meters of the set by INIG	25% H2 for G10 Sagemcom and G65ELSTER and 100% H2 for G16 Sagemcom and G40 ELSTER: INIG											all the meters of the set by INIG	25% H2 for ELSTER and 100% H2 for Sagemcom : INIG					all the meters of the set by INIG
DNV, CESAME,GRT GAZ, ENAGAS, GAS SYSTEM	set 4	25% INIG	all the meters of the set by INIG	100% H2 for G4/G6 and 25% for G25 INIG																	all the meters by INIG

Table 18. Planning for DSO meters

2.3. Test protocols and procedures for water dew point sensors

Testing and calibration of trace water sensors (water dew point sensors or UUT as called later) in the test campaign in task T3.3 will be carried out exclusively at INRIM partner. It is not possible to perform Interlaboratory Comparisons (ILCs) in this case. Given that INRIM is the Italian National Metrology Institute, this underscores its competence and guarantees the reliability of the research results.

Table 19 outlines the schedule for testing and calibration of water dew point sensors and analysers.

Table 19. Planning for water dew point sensors.

Sensor Technology	Sensor Owner	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M9	M10	M11	M12	M13	M14	M15
TDLAS	SNAM	AIR/N2									AIR/N2	H2						H2
Ceramic Metal-Oxide Moisture Sensor	GAZ-SYSTEM	AIR/N2									AIR/N2	H2						H2
TDLAS	SNAM	AIR/N2									AIR/N2	H2						H2
Ceramic Metal-Oxide Moisture Sensor	GAZ-SYSTEM	AIR/N2									AIR/N2	H2						H2
Aluminum Oxide Sensor	INRIM	AIR/N2									AIR/N2	H2						H2
Aluminum Oxide Sensor	INRIM	AIR/N2									AIR/N2	H2						H2

The test methodology includes the following steps:

- Month 0. First calibration of the Units Under Test (UUTs) according to the common (or current) practice used to calibrate these UUTs, i.e., calibration at approx. 1050 hPa, in air or nitrogen (N_2) as gas carrier at three calibration points, as identified in the Table 20 below, by comparison to a primary humid gas generator or equivalent.
- Duration: 8 months. Re-installing the UUTs in the field subjected to normal operation in NG or H2/NG blends.
- Month 9 first half. Second calibration of the UUTs according to the common practice to investigate possible drift effects due to NG or H2/NG blend exposure in the field.
- Month 9 second half. First calibration of the UUTs according to the revised practice: simulation of an on-site calibration by comparison to a novel deployable humidity calibration system for moist H_2 operating from 0.2 MPa to 5.5 MPa. The calibration points are identified in the Table 20 below.
- Duration: 5 months. Re-installing the UUTs in the field subjected to normal operation in NG or H2/NG blends.
- Month 15. Second calibration of the UUTs according to the revised practice to investigate possible drift effects due to NG or H2/NG blends exposure in the field.

Table 20. Suggested calibration points (water vapour amount fractions and corresponding frost point temperatures).

Common practice (CP) calibration		Revised practice (RP) calibration	
Frost point temperature at 1.1 bar(a) in air/N_2	Water vapour mole fraction	Frost point temperature at 1.1 bar(a) in H_2	Frost point temperature at 2.5 MPa(a) in H_2
-40 °C	**117 ppm**	-40 °C	-10 °C
-50 °C	**36 ppm**	-50 °C	-22.5 °C
-60 °C	**10 ppm**	-60 °C	-35 °C

2.4. Testing protocol for flow computers

Around 100 different models of flow computers are installed in gas grids of TSO participating in the project. Nevertheless, just two equations of state are currently implemented in these devices for compressibility factor calculation:

- AGA8 / EN ISO 12213-2 [4].
- SGERG88 / EN ISO 12213-3 [5].

Therefore, the testing protocol focuses on the evaluation of these compressibility factor calculation methods. For estimating the error of tested methods, the results will be compared with the values obtained with other reference method.

Additionally, a flow computer will be tested to analyze its performance for different hydrogen concentrations (inside and outside of limits defined in standards).

After a revision of partners capabilities and availability for planned activities, capabilities of INIG and Enagás are identified for testing protocol defined following.

As advanced previously, the testing protocol is separated in two activities.

2.4.1 Compressibility factor calculation

This activity will be performed by INIG with Enagás collaboration in intercomparison task. Both partners will use own tools with the implementation of equations of state defined in the corresponding standard.

Initially, a revision of hydrogen admissible values defined in existing compressibility factor calculation methods will be performed.

Error evaluation of current implemented methods AGA8 and SGERG-88 will be performed for:

- NG:H2 admixtures up to 30 vol-% of hydrogen, using as initial approach the reference method indicated in Table 21.

- Pure hydrogen, using as initial approach the reference method indicated in Table 22 or other valid identified for pure hydrogen.

Table 21. Error evaluation for compressibility factor calculation up to 30 vol-% H_2 in natural gas.

Tested method	Reference method
AGA8 (EN ISO 12213-2)	GERG2008
SGERG88 (EN ISO 12213-3)	

Table 22. Error evaluation for compressibility factor calculation at 100 % H_2.

Tested method	Reference method
AGA8 (EN ISO 12213-2)	SGERG-mod-H2 or other valid for pure hydrogen
SGERG88 (EN ISO 12213-3)	

Conditions for calculations are defined below:

- NG:H2 admixtures up to 30 vol-% of hydrogen:
- 3 natural gas compositions (Gas 1 described in EN ISO 12213-2 and other 2 representative compositions of European gas grid) with 5 concentrations each of hydrogen in the range 0/10-30 vol-%.
- 15 values of temperature in the range 263-338 K.
- Pressure every 5 bar in the range 1-12 MPa.
- Pure hydrogen:
- 1 composition (100 % H_2).
- 15 values of temperature in the range 263-338 K.
- Pressure every 5 bar in the range 1-12 MPa.

For the purpose of interlaboratory comparisons (ILC) calculations of selected points (at least 6 points for tested methods AGA8, SGERG88 and GERG2008) will be performed with Enagás and INIG. Calculations will be made based on the composition of Gas 1 from the EN ISO 12213-2 standard. ILC acceptance criterion is established in the same compressibility factor value to 5 decimals.

2.4.2 Flow computer testing

This activity will be performed by Enagás. Selected flow computer is representative of TSO partners gas grids and additionally to the methods AGA8 and SGERG8 the device has EU-type examination certificate for a method valid for pure hydrogen.

Compressibility factor calculation methods to be tested will be the following:

- AGA8.
- SGERG-88.
- Hydrogen gas (H_2) table.

Conditions for testing are defined below:

- NG:H2 admixtures up to 30 vol-% of hydrogen (use of AGA8 and SGERG88):
  - 2 natural gas compositions with 5 concentrations each of hydrogen in the range 0-30 vol-%.
  - 5 values of temperature in the range 263-338 K.
  - 5 values of pressure in the range 1-12 MPa.
- Pure hydrogen (use of hydrogen gas (H_2) table):
  - 1 composition.
  - 5 values of temperature in the range 263-338 K.
  - 5 values of pressure in the range 1-12 MPa.

2.5. Test protocols and procedures for leak detectors

In the leak detectors testing two different project partners are mainly involved: FBK, which leads this subtask, and INIG. INIG provides support in this activity by testing ultrasonic gas leak detectors and by repeating some measurements of the leak detectors tested by FBK for inter-laboratory comparison and validation of both the test protocol here proposed and the obtained results. The test benches/rigs available at the FBK and INIG for testing gas leak detectors are described in detail in D3.1 and will be used to test the sensors mentioned in D2.1 and in the first section of this document.

2.5.1 Premise and Motivations

The standards that currently regulate performance requirements, related tests, selection procedures, installation, use, and maintenance of gas sensors for monitoring explosive atmospheres are the BS EN 60079-29-1 [6] and BS EN 60079-29-2 [7]. Furthermore, fixed ultrasonic gas leak detectors are regulated by the BS EN 50724 standard [8]. The existing standards provide comprehensive guidelines for testing and selecting sensors suitable for detecting explosive atmospheres in common applications. However, the introduction of hydrogen/natural gas blends into the grid introduces new variables and challenges. These factors should be considered in the guidelines to properly assess sensor performance for monitoring potential leaks of hydrogen/natural gas blends at various concentrations and component ratios. In particular:

i) Different ratios of H2/NG in air lead to different lower flammable limits (LFL) and upper flammable limits (UFL).

Table 23. table showing the different LFL and UFL values at different CH_4/H_2 ratios [10].

hydrogen fraction in fuel gas blend	Methane/hydrogen			natural gas/hydrogen		
	LEL	UEL	LOC	LEL	UEL	LOC
0 mole%	4.2	16.6	10.1	3.8	16.2	9.7
5 mole%	4.2	17.4	9.8	3.8	17.2	9.7
10 mole%	4.2	18.2	9.6	3.8	17.8	9.4
25 mole%	4.2	21.2	9.1	4.0	21.0	8.9
50 mole%	4.0	29.0	7.9	3.8	28.4	7.6
100 mole%	4.1	75.6	4.3	4.1	75.6	4.3

Therefore, the accurate evaluation of the actual composition of H2NG mixtures is of paramount importance to evaluate correctly the LFL and UFL, and to provide alarms at appropriate LFL and UFL%. Since, as stated in [6], except for IR sensors, the current available sensing technologies lack selectivity to a specific flammable gas in a mixture of flammable gases. Therefore, a specific evaluation on the sensing performance of a device dedicated for H_2/NG blends leak detection is necessary.

ii) Even though the ratio of H_2 and NG (mainly CH_4) in the grid should be known, the different chemical and physical properties of the two gases (including diffusivity in materials) can result in unpredictable variations in their ratio. Therefore, a device calibration based on a fixed H2NG is not sufficient. Devices should either quantitatively detect both components and/or be able to provide a LFL warning based on the potentially more explosive H2NG concentration.
i) Current standards highlight that only sensors that are intended to be used for monitoring exclusively hydrogen should be calibrated using hydrogen as calibration gas [7]. In the case of H2NG leakage monitoring, this standard should be expanded since it would be no longer adequate for the specific application.
ii) H_2 is a strong reducing gas that can poison/degrade the components of a sensor device. Therefore, the stability of sensors intended to be used for monitoring H2NG leakages, even though focus just on the evaluation of NG (CH_4) concentrations, must be subjected to H_2 too within the stability tests.

Based on the upon premises, the present test protocol is focused on measurements that might be useful to evaluate the performance of explosive atmosphere detectors. The suggested tests outlined by the current standards, which are not expected to be impacted by the presence of an H2NG mixture in air, as opposed to the presence of NG or hydrogen alone, will not be carried out [6, 7]. They include, for instance: orientation tests, vibration tests, drop tests, etc.

The testing protocol is divided into two main parts: test methods for gas detectors (Section 2.4.2) and test methods for fixed ultrasonic gas leak detectors (Section 2.4.3).

2.5.2 Test methods for gas detectors

The following test methods are valid for fixed, transportable, and portable gas detectors, unless otherwise specified. Furthermore, they are intended to be valid for both aspirated equipment and devices operating by gas diffusion, unless stated otherwise.

General requirements and normal conditions for tests

All normal conditions and general requirements for testing are in accordance with standards [6, 7] and manufacturer claims unless stated otherwise. They include standard test gas, flow rate for test gases, temperature, humidity, pressure, and acclimation time for the devices. In particular, ambient air and test gas shall be held at a temperature constant of ±2 °C within the range of 15 °C to 25 °C, throughout the duration of each test, unless otherwise specified for the particular test. Concerning humidity, the ambient air, zero gas and test gas shall be held at a relative humidity (RH) over the range 20 % to 80 % throughout each test unless otherwise specified for the specific test. The humidity of zero gas and test gas shall be controlled to within ±10 % RH.

The test methods and procedures described in this section are intended to serve as a basis for establishing whether the equipment conforms to the supplementary performance requirements given in Annex A of the current standard [6].

Preparation of equipment and test rig before testing

The equipment shall be prepared and mounted as near to typical use as possible, in accordance with the instruction manual, including all necessary interconnections, initial adjustments, and initial calibrations. Adjustments may be made, where appropriate, at the beginning of each test. During each test, no adjustment shall be made. The suppression of indications of the equipment under test shall be disabled.

The test rig shall be prepared according to the guidelines outlined in [6], Annex B.

Test method

Calibration curve

As a reference point, the equipment intended for NG leakage detection shall be exposed to NG or CH_4, at 0%, 10%, (30%), 50%, (70%) and 90% (redundant, their execution is at the discretion of the test performer) of the measuring range, starting with the lowest and finishing with the highest of the selected volume fractions. However, the highest volume fraction may be reduced for equipment with low measuring ranges to prevent over-range indications within the performance limits. This operation shall be carried out three times consecutively.

Afterward, the same measurement shall be repeated using H_2/CH_4 mixtures with three different rations of H_2/CH_4, i.e., 10/90%, 50/50% and 100/0%.

If the equipment is initially intended to monitor H_2, the measurement must be performed using as a reference H_2, at 0 %, 10 %, (30%), 50%, (70%) and 90% (redundant, their execution is at the discretion of the test performer) of the measuring range, starting with the lowest and finishing with the highest of the selected volume fractions. Then, the measurement shall be repeated using the same H_2/CH_4 blends proposed above.

Calibration curves should then be compared to evaluate the impact of the H_2/CH_4 blend used on the performance of the device.

In the case of equipment intended for the quantification of both NG (CH_4) and H_2 components, the reference point test can be carried out indiscriminately starting from pure CH_4 or H_2.

Equipment with semiconductor or catalytic sensors shall then be exposed to the test gas with a volume fraction between 45% to 55% of the measuring range for (60 +2/0) minutes, and the deviation of the indication during the exposure should be measured.

Stability measurement

Short term stability

The equipment shall undergo six cycles of exposure to the standard test gas (either CH_4 or H_2) for 3 minutes, followed by exposure to clean air for a period of 7 minutes. Indications shall be taken at the end of each exposure to clean air and the standard test gas. The same measurement procedure shall be repeated using H_2/CH_4 mixtures with three different rations of H_2/CH_4, i.e., 10/90%, 50/50% and 100/0%.

Long-term stability (fixed and transportable equipment – Group II only)

The equipment shall be operated continuously in clean air for a period of (63 ± 1) days. On the eighth day, the equipment shall be exposed to the standard test gas (either CH_4 or H_2, depending on the device's aim) for a duration of (480 +10/0) minutes. Then, the same measurement shall be repeated using H_2/CH_4 mixtures with three different rations of H_2/CH_4, i.e., 10/90%, 50/50% and 100/0%. Indications shall be taken prior to the application of test gas, after stabilization of the reading and prior to the removal of test gas. At the end of each subsequent (7 ± 1) day period, the equipment shall be exposed to the standard test gas and to gas mixtures until the reading has stabilized. Indications shall be taken prior to the application of test gas and after stabilization of the reading.

Long-term stability (portable equipment – Group II only)

The equipment shall be operated continuously in clean air for a period of (420 +5/0) min and then exposed to both the standard test gas (either H_2 or CH_4, depending on the device's aim) and H_2/CH_4 mixtures. Each gas exposure should stand for another (60 +5/0) min. Then indications shall be taken prior to the application of test gas, after stabilization of the reading and prior to removal of test gas. The equipment shall then be operated in clean air continuously for a period of (480 +10/0) min per working day over a total of 19 consecutive working days. The equipment shall be exposed to the standard test gas and to H_2/CH_4 mixtures until the reading has stabilized, once at the end of each operating period. Indications shall be taken prior to the application of test gas and after stabilization of the reading.

Alarm set point(s)

Rising concentration

For equipment with adjustable alarm set points, set the alarm set point at 10% relative below the concentration of the standard test gas. The equipment shall be adjusted with clean air and standard test gas or the specified test gas. Then expose the equipment to clean air followed by the standard test gas (CH_4) or the specified test gas until alarm activates or twice the respective $t(90)$ is reached, whichever is less.

For equipment with several alarm set points, this test shall be carried out for each alarm set point.

The measurements should be repeated using H_2/CH_4 mixtures with three different rations of H_2/CH_4, i.e., 10/90%, 50/50% and 100/0%.

Humidity of test gas

The test shall be conducted at a temperature of (30 ± 2) °C. Following an acclimation period of at least 2 hours at 30°C, the equipment shall be calibrated and adjusted in accordance with the instruction manual and manufacturer specifications. The sensor shall be exposed for (60 +5/0) min to clean air humidified to (20 ± 5) % RH. The sensor shall then be exposed to four different rations of H_2/CH_4 mixtures, i.e., 0/100%, 10/90%, 50/50% and 100/0%, all of them humidified to (20 ± 5) % RH until stabilized. The procedure shall be repeated with humidities of (40 ± 5) % RH and (80 ± 5) % RH. The concentration of the test gas shall be held constant, or allowance of changes in its concentration by dilution in water shall be made.

All relative humidity shall be considered as water vapour volume fractions at the nominal temperature of 30°C.

Time of response

The equipment shall be switched on in clean air and, after an interval corresponding to at least two times the warm-up time, as stated by the manufacturer, without switching off the equipment or sensor(s), it shall be subjected to step changes from clean air to the standard test gas and from standard test gas to clean air. These changes shall be introduced by means of suitable equipment (see Annex B of [6]). The times of response $t(50)$ and $t(90)$ for increasing concentration, and $t(50)$ and $t(10)$ for decreasing concentration, shall be measured. This measurement procedure shall be repeated for all four different H_2/CH_4 gas mixtures (0/100%, 10/90%, 50/50% and 100/0%), diluted in air.

High gas concentration operation above the measuring range

This test should be applied to all equipment with an upper limit of the measuring range of less than 100% (v/v) gas. The sensor shall be subjected to the test using equipment that simulates a step change between gas concentrations, such as those described in [6], Annex B.

The sensor shall be exposed to a step change from clean air to a volume fraction of 100% (v/v) gas, which shall be maintained for (180 + 5/0) s.

Any gas concentrations exceeding the full-scale limit shall be indicated by a full-scale indication and, if available, an alarm. If the indication is digital, a clear indication shall be given that the upper limit of the measuring range has been exceeded. All gas alarms must remain operational at all gas concentrations above the full-scale limit. If the equipment provides a latching alarm feature, the latching feature shall be verified during and after exposure to the high gas concentration.

The measure shall be repeated for three different H_2/CH_4 gas mixtures (0/100%, 50/50% and 100/0%).

Poisons

Due to the very strong reducing effect of H_2 and its potential to adversely affect sensor devices, investigations into the gas's potential poisoning effects on sensors are necessary. Specifically, the equipment shall be exposed to volume fractions of 50% and 100% H_2, either mixed with CH_4 or N_2, in continuous operation for 240 minutes. Following this exposure, a short-term stability measurement using CH_4 will be repeated to verify any potential decline in the sensor performance.

Additional notes

If, for safety reasons related to the test rig used, it would not be possible to perform measurements at concentrations higher than LFL, measurements will be performed at lower concentrations lower. For instance, calibration curves will be performed at concentrations that are 0%, 10%, 50% and 90% of the LFL.

In all measurements, the gaseous carrier (complement to CH_4 and/or H_2) shall be either air or N_2.

2.5.3 Test methods for fixed ultrasonic gas leak detectors

The following test methods are valid for Ultrasonic Gas Leak Detectors (UGLDs) that operate at frequencies beyond the audible range. UGLDs are increasingly used to swiftly detect gas leaks from pressurized systems, complementing point or line of sight detectors. These detectors identify the acoustic emissions produced by leaks, propagating omnidirectionally at the speed of sound. UGLDs improve response times for identifying hazardous gas leaks by sensing the ultrasonic noise generated by pressurized gas leaks. The effective range of an UGLD depends on the gas leak's rate, atmospheric transmission of ultrasound, and potential acoustic background noise. Physical obstructions between the leak location and the UGLD can also impact the detector's effective detection range.

This section does not apply to portable gas detectors using ultrasonic measurements nor to gas detectors using non-ultrasonic measurements to detect a gas leak.

General requirements and normal conditions for tests

All normal conditions and general testing requirements refer to standards [8] and manufacturer claims, unless specified otherwise. These include standard test gas, flow rate for test gases, temperature, humidity, pressure, and acclimation time for the devices.

The test methods and procedures described in Section 3.3 serve as the foundation for determining whether the equipment conforms with the requirements outlined in the current standard [9].

Preparation of equipment and test rig before testing

The equipment shall be prepared and mounted as closely to typical use as possible, in accordance with the instruction manual, including all necessary interconnections, initial adjustments and initial calibrations. Adjustments may be made, where appropriate, at the beginning of each test. During each test, no adjustment shall be made. Suppression of indications of the equipment under test shall be disabled.

For test gases, compounds that mimic the behaviour of the target gases detected by UGLDs may be used. As mentioned in [8], "*The gasses to be used for the test shall be Nitrogen, > 99,5 % v/v, or compressed dry air simulating the target gas. Alternatively, tests may use a typical reference gas considering the use case, non- dangerous gas shall be used, while representing the gas type*". Typically, N_2 is used to simulate CH_4, while helium (He) is used to simulate H_2.

Test method

Measurement Range

Due to the operating method of ultrasonic detectors, their operating range should be assessed not in terms of gas concentration, but in terms of the leak size and gas pressure at which the leak occurs. The study will examine the following gas flow values:

- the lower detection limit declared by the manufacturer,
- 10%, 20%, 30%, 50%, 75%, and 100% of the upper detection limit declared by the manufacturer.

Initially, the tests will be conducted for pure methane or nitrogen, and then they will be repeated for methane-hydrogen or alternatively (nitrogen-helium) mixtures with hydrogen/helium contents of 10%, 20%, 50%, and 100%.

The planned measurement series will be carried out for three pressure values ranging from 1-10 bar.

Each measurement will be conducted three times.

Response Time

The study should be conducted for the lower and upper detection limits confirmed during the measurement range assessment on pure methane/nitrogen and pure hydrogen/helium, as well as a mixture of 50% methane - 50% hydrogen (or nitrogen 50% - helium 50%). During the tests, ensure that the noise level at the workstation does not exceed 55 dB.

Interferences

During the tests, evaluate the impact of barriers and existing noise on the device's operation. For this purpose, similar tests to those for the measurement range assessment will be conducted at a workstation where:

- there is a 15 mm plastic barrier between the device and the leak location,
- the noise level not associated with the generated leak exceeds 85 dB.

2.5.4. Interlaboratory comparison

To evaluate the suitability of the testing protocol, three specific measurements will be replicated at both FBK and INIG gas test benches using three of the detectors scheduled for testing. A comparison of the data collected at the two different test sites will be carried out for testing protocol validation. The three tests that will be reproduced for the interlaboratory comparison are: i) calibration curve; ii) short term stability; and iii) alarm setpoint check.

2.5.5 Scheme and timeline of the test protocol for leak detectors

The scheme depicted in Figure 2 summarizes the approach that will be adopted in the test protocol, while Figure 3 shows the tentative timeline for the execution of the tests (WP3).

Figure 2. Schematic of the approach that will be used in the test protocol for the characterisation of leak detectors.

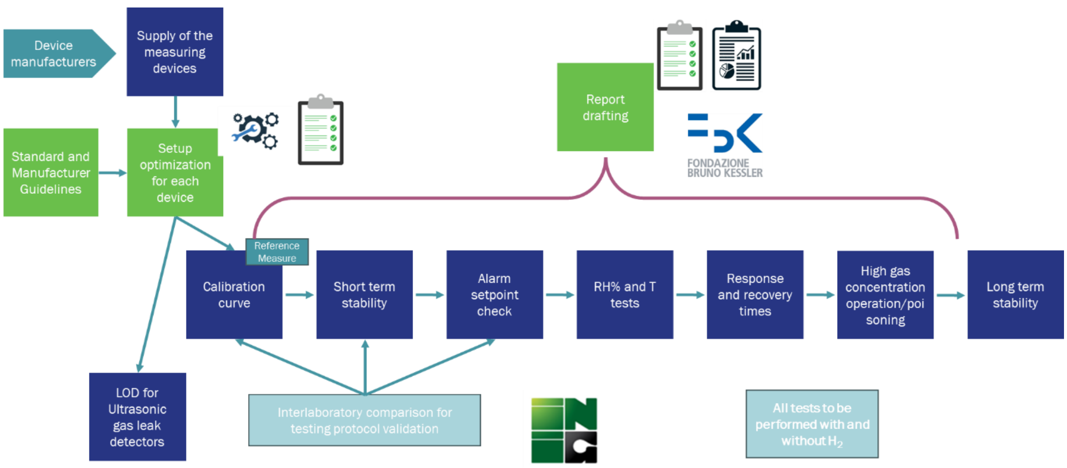


Figure 3. Tentative timeline for the execution of leak detector tests.

Type of test	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Setup optimization													
Calibration curve													
Short term stability													
Long term stability													
Alarm setpoint check													
RH% and T tests													
Response and recovery evaluation													
High gas concentration operation													
Interlaboratory comparison (INIG)													
Ultrasonic detector LOD tests (INIG)													
Poisoning													
Report drafting													

3. Conclusions

Deliverable D2.2 details the comprehensive testing frameworks designed to assess the performance of gas measurement devices in environments that contain H2 and H2NG mixtures. This document outlines improvements made to methodologies and protocols to better address the challenges associated with H2 usage. The main sections include:

- **Section 1**: Provides a detailed list of the devices selected for testing, including gas meters, pressure transmitters, leak detectors, water dewpoint analysers, and flow computers. It highlights the criteria for their selection and underscores the importance of these devices in understanding the reactions with H2NG mixtures and preparing for precise testing.
- **Section 2**: Outlines the testing protocols developed for the ageing, calibration, and testing of the identified devices. This section is essential, detailing the specific tests each device will undergo to ensure reliable performance in hydrogen-enriched environments. In conclusion, Deliverable D2.2 provides a comprehensive understanding of the performance of these critical devices under altered gas compositions. The methodologies detailed in this document represent a strong foundation for policymaking, the development of industry standards, and further research, thereby advancing the energy sector's transition towards sustainable practices.

4. References

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[9] Askar E., Schröder V., Schötz S., Seemann A. Power-To-gas: Safety characteristics of hydrogen/natural-gas mixtures (2016) Chemical Engineering Transactions, 48, pp. 397 – 402.

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