HyDelta

WP1D – Flow measurement of hydrogen

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Executive Summary

The suitability of measurement principles for small consumption meters capable of measuring hydrogen was investigated based on gas characteristics, the measurement technology and availability. The availability of the meters was investigated through interviews with meter suppliers. Based on the results, ultrasonic meters and thermal mass flow meters were the preferred options for selecting hydrogen meters for household pilot projects.

Due to the low density and viscosity of the gas, it is possible for the flow in a hydrogen meter to change between laminar and turbulent. At the present, it is not known how the meters derive the correct flow pattern when calculating the quantity of gas. In addition, there are major differences in gas properties between hydrogen and air, the gas that is used for field testing the meter. This can cause large differences in the pressure difference across the meter. For the time being, it is assumed that the recently completed first European Type Approval according to MID has verified these two aspects.

Hydrogen of distribution quality may contain gaseous impurities. The thermal conductivity of these impurities differs from that of hydrogen to such an extent that even the permissible quantities result in a change that is within the order of magnitude of the accuracy class of the thermal mass flow meter. Here, too, it is tentatively assumed that this aspect has been verified during the European type approval according to the MID of this type of meter. When hydrogen meters are evaluated by network operators, it is useful to examine the three aspects mentioned above in more detail.

The distribution network operators work together within the Meter Pool Small Consumers (Meter Pool KV) to monitor the quality of gas meters. Hydrogen is not yet considered in the Meter Pool KV. Proposals for extending the texts for the purpose of adapting the KV Metering Regulations and the related Implementing Provisions and Work Instructions on hydrogen have been included in this report. In addition, it is also necessary to adapt control installations in order to be able to inspect hydrogen meters.

In Europe, there is not yet a traceable chain for measuring hydrogen flow. Traceability refers to a continuous series of comparative measurements that use a known national or international standard as a reference for the measurement results of an instrument. Some important steps for traceability have been taken, for example the establishment of a control installation for hydrogen meters at TÜV in Glasgow that can add gaseous impurities. A specification from this kind of an installation has been included in this report. Making hydrogen meters in the Netherlands traceable is expected to increase confidence in the quantity measurement of hydrogen.

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1. Rationale

The most important conclusion from the research “Future-proof gas distribution networks” (Kiwa Technology, commissioned by Netbeheer Nederland, 2018) is that, with the right measures, the existing gas network provides an excellent solution for distributing sustainable gases such as 100% hydrogen. One important focus area is the billing of gas and therefore the measurement of the hydrogen amount.

Netbeheer Nederland has drawn up a project plan entitled “Measuring and Calculating Hydrogen” (M&VH2). The aim of this plan is to have a sufficient number of meters available by 2024 (provisionally set at 1,500) and to provide insight into how hydrogen meter installation should be scaled up from 2030 onwards. This work package is based on the intention of each distribution network operator having its own hydrogen network in operation by 2024. In these networks, hydrogen is measured correctly, reliably and safely, and data from smart meters is made available for the billing of hydrogen.

However, a number of challenges need to be overcome before hydrogen can be measured and calculated with the same ease, reliability and safety as natural gas.

The meters currently installed at small consumer locations are mainly bellows meters. The gas flow drives a mechanism in these meters. Since hydrogen has only 1/3 of the energy density of Groningen’s natural gas, bellows meters with hydrogen will either have to run three times faster, or the meter will have to be larger. In the first case, this may lead to additional noise production and in the second case, the meter will in most cases no longer fit in the standard meter box. Existing gas meters for natural gas cannot be used for hydrogen. For this reason, in addition to bellows gas meters, alternative measurement principles will have to be investigated.

The network operators randomly check the metrological quality of their meters with traceable test equipment. For practical reasons, air is the test medium used. A factor is used for converting the metrological deviation with air to natural gas, but for air to hydrogen the translation has not yet been disclosed by the meter suppliers. Therefore, traceable inspections for hydrogen meters does not yet exist.

It is expected that the hydrogen distributed will not be completely pure. International standards and Netbeheer Nederland assume a hydrogen content of at least 98%. As the other 2% of gases have very different properties as compared to hydrogen, their effects on any deviation in ultrasonic and thermal meters can be significant when compared to European metrological requirements. It can be expected that the meter will be tested with the other gases.

At hydrogen purities close to 100%, there is a direct relationship between the energy content of hydrogen and the amount of cubic metres consumed. This makes it possible to bill the end user in kWh, allowing for a direct comparison with electricity consumption. However, this approach requires adjustments to the billing method commonly used in the Netherlands. The purity of the hydrogen in the network may in fact be lower, but no practical values are available as of yet.

The Dutch distribution network operators use a quality system for energy meters for small consumers. The system is described in the KV Metering Regulations and has been agreed upon between Netbeheer Nederland and the Radiocommunications Agency Netherlands, the supervisory body for the Dutch Metrology Act (Metrologiewet). Hydrogen meters are not yet part of this system. The installation of approved energy meters and traceable inspections of energy meters are specified in the KV Metering Regulations. These provisions will also apply to hydrogen meters in the future.

For this work package, information was exchanged with the M&VH2 project, and information from the coordinating board of the Meter Pool KV and Standardisation of Gas Metering was used. These projects are carried out on behalf of Netbeheer Nederland.

2. Objective

The following targets have been specified for HyDelta's "Gas Metering" work package.

In addition to the suitability of bellow gas meters for hydrogen, this report provides insight into the suitability of gas meters that measure the speed of the gas flow instead of the volume. These are ultrasonic gas meters and thermal mass flow meters. The outer dimensions of these meters do not depend on their capacity and they produce less noise. For hydrogen, these meters are currently under development by European gas meter manufacturers. It is important for hydrogen meters that are suitable for the Dutch situation to become available on the market in good time.

Establishing the basic knowledge required for installing these meters in new and existing meter boxes, allowing for regulations pertaining to safe installation to be defined in time for installers.

Providing insight into the composition of hydrogen in Dutch gas networks with the expected impurities, allowing the effects on the metrological accuracy of the meters to be calculated in advance.

Defining the implementation process for the method chosen to check the traceability of ultrasonic and thermal hydrogen gas meters and to include them in the quality system for small consumer energy meters. The activities considered here are the same as the activities that apply to gas meters in the Netherlands. In other words, assessment of an application by a meter manufacturer for a Dutch meter code (which is only honoured with proof of a European MID – authorisation for hydrogen), the metrological incoming goods check of the meters at the network operator, the metrological control after one year and the mandatory metrological random check taken every five years.

3. Suitability of the metering principles

3.1 Method of assessing the metering principles

In addition to the traditional bellows gas meters, ultrasonic gas meters are also used in the Netherlands. In contrast to a bellows meter, an ultrasonic meter uses an acoustic gas property, the speed of sound. One type of gas meter that is not yet used in gas distribution in the Netherlands is the thermal mass flow meter. This meter type uses the thermal conductivity of the gas.

Natural gas consists largely of methane, but air is used to check the gas meters for practical reasons. In terms of the above-mentioned gas properties, hydrogen is quite different from the more "conventional" gases, such as methane, nitrogen and oxygen. By comparing the properties of the different gases, this chapter provides a picture of what we can expect from hydrogen meters and the way they will behave with these gases. Based on the differences observed, proposals will be created for evaluating hydrogen meters.

3.2 Gas properties

The properties of hydrogen differ greatly from those of conventional gases. The most important properties are as follows:

Energy content

Hydrogen contains less energy per m^3 of gas than natural gas or methane (See Table 1).

Table 1 Energy content of hydrogen and natural gas

Gas	Energy content (lower value) MJ/m^3
Hydrogen	10.78
Methane	35.90
Groningen gas	31.65
Ratio	31.65/10.78=2.94

Table 1 shows that at the same power level, almost three times as much hydrogen volume flows through a bellows meter than in the case of low-calorific Groningen natural gas.

Sound velocity

Traditionally, natural gas meters are metrologically tested with air for safety reasons and due to the small differences between the properties of natural gas and air. An ultrasonic meter is able to determine the sound velocity of a gas by sending the sound wave back and forth in the gas flow. An ultrasonic meter can distinguish the difference between natural gas and air. The noise speeds are indicated in Table 2.

The speed of the gas and the speed of sound are determined by the time difference between the sound wave travelling back and forth and the angle that the sound wave makes with the measuring tube (automatic calibration of the meter).

The *time of flight* of the sound wave between the transducers is shortened with hydrogen. One manufacturer claims to be able to supply an ultrasonic meter that can measure both natural gas and hydrogen. This meter would need to be constructed in such a way that the sound wave during operation with natural gas and hydrogen contacts the transducers accurately in both cases. When the reflection of the sound wave diminishes, the meter automatically increases the amplification of the sound, which is detrimental to battery life. The frequency at which the sound waves are produced must also be sufficiently high in order to measure the high speed of sound in hydrogen correctly.

In discussions within Working Group 9 (Ultrasonic Meters) of CEN/TC 237, these changes for hydrogen to existing gas meters have been regularly discussed. The outcome is that the existing ultrasonic technology can also be used for hydrogen.

Due to the large difference between the sound velocity of hydrogen and that of other gases, the sound velocity of hydrogen changes significantly with respect to the accuracy class of the meter when those other gases are present in small quantities in the distribution network. The effect of 2% inert gases on the sound velocity is shown in Table 2.

Table 2 Comparison of sound velocity in different gases, and the change in sound velocity of hydrogen due to the presence of inert gases, according to ISO 16487 and Netbeheer Nederland specifications

gas	sound velocity m/s	ISO 14687 / NBNL share	average sound velocity m/s	difference compared to H_2
air			343	
L-gas (G25)*			432	
H_2	1270			
N_2	349	2%	1252	-1.45%
CO_2	267	2%	1250	-1.58%
CH_4	446	1.50%	1258	-0.97%
O_2	326	0.50%	1265	-0.37%

*L-gas is the G25 reference gas for testing appliances with low-calorific gas according to EN 437. It is a mixture of 14% nitrogen and 86% methane. G25 is used here because of it is composed of only two components

Table 2 shows that sound velocity in hydrogen is 3.7 times higher than in air. The frequency of the sound pulses must be high enough to continue measuring accurately at higher sound velocities.

The average sound velocity in the mixed gases is determined using the percentage share of the gas components. The change in the sound velocity due to the presence of a small percentage of nitrogen, carbon dioxide or methane in hydrogen is comparable to the accuracy[1] of the meter (1.5%).

An ultrasonic meter can determine the sound velocity of the gas through which it is flowing. The meter detects contamination, but is unable to define the gas with which the hydrogen is contaminated.

The software of the hydrogen meter needs to specify the sound velocity in air so that the meter can recognise the gas during a metrological inspection.

[1] The accuracy class of gas meters installed for small consumers in the Netherlands is usually 1.5. This means that the metrological discrepancy would be within an interval of -1.5% to 1.5%.

Thermal conductivity

The effect of 2% inert gases, methane and oxygen on thermal conductivity is shown in Table 3.Table 3 Change of thermal conductivity due to presence of inert gases, according to ISO 16487

gas	thermal conductivity W/mK	ISO 14687 / NBNL share	average thermal conductivity W/mK	difference compared to H_2
air			0.0269	
L-gas (G25)			0.0327	
H_2	0.174			
N_2	0.024	2%	0.171	-1.72%
CO_2	0.015	2%	0.171	-1.83%
CH_4	0.0341	1.50%	0.172	-1.21%
O_2	0.0263	0.50%	0.173	-0.42%

Table 3 shows that the thermal conductivity of hydrogen is more than three times that of air. The thermal mass flow meter will need to be know the type of gas flowing through the instrument.

The change in thermal conductivity due to the presence of a small percentage of nitrogen or carbon dioxide in hydrogen is significant compared to the accuracy[2] of the meter (1.5%). A thermal mass meter cannot correct for this influence unless the gas composition is known beforehand or is constant.

Density and viscosity

One of the ways to characterise the flow pattern in a channel is with the Reynolds number (Re). Re is dimensionless. Two different flows that have the same Re are comparable. Re also indicates whether a flow is laminar or turbulent. The density and viscosity of the gas play an important role in calculating the Re.

As far as the flow pattern is concerned, Re says the following:

- If Re<2040 the flow is laminar
- If Re>4000 the flow is alternatively laminar and turbulent
- If Re>5000 the flow is typically, but not necessarily, turbulent

[2] The accuracy class of gas meters installed for small consumers in the Netherlands is usually 1.5. This means that the metrological discrepancy would be within an interval of -1.5% to 1.5%.

Laminar and turbulent flow have a different velocity distribution. The distribution of speed over the diameter of a pipe is shown in red in Figure 1.

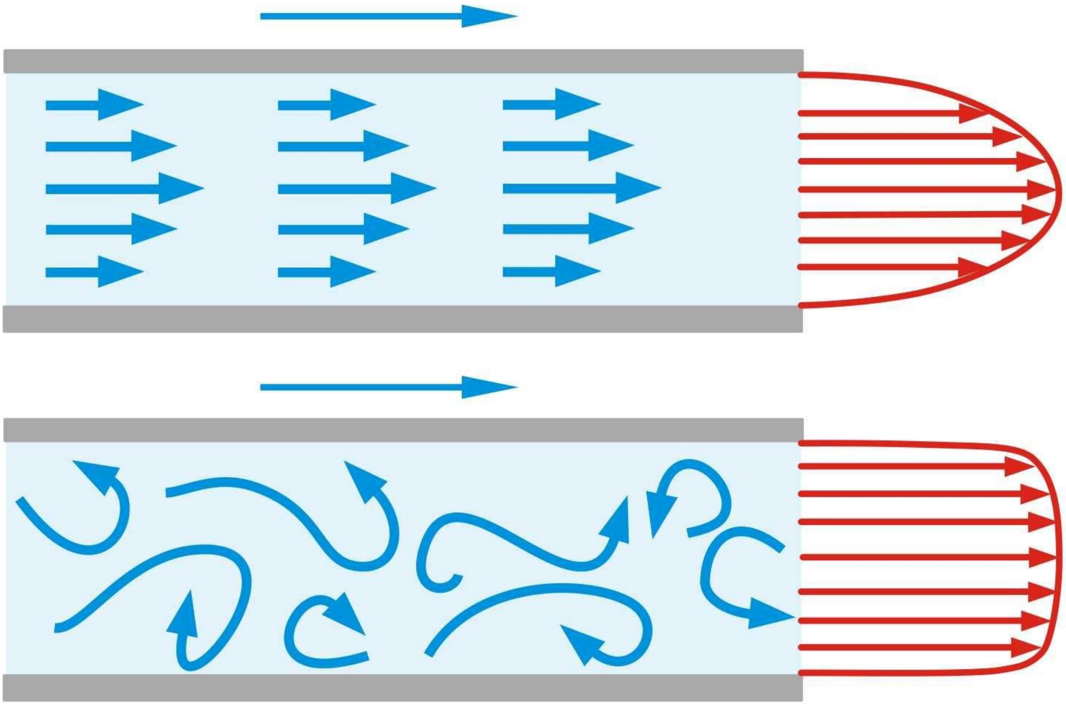

Figure 1 Speed distribution in laminar flow (top, parabolic) and turbulent flow (bottom)

When determining the size of the gas flow in speedometers, the correct speed distribution through the meter shall be assumed.

To determine the nature of the flow in a thermal mass flow meter or ultrasonic meter, a comparison was made between operating the meter with hydrogen and checking it with air. For the measuring points of the Meter Pool KV (Q_{max} and $0.2*Q_{max}$), Re were calculated for both gases. The four outcomes, valid at the pressure comparable in a household gas meter, are given in the Table 4.

Table 4 Example of Reynolds number for hydrogen and air at Q_{max} and $0.2*Q_{ma}$ for flow in a gas meter for small consumers.

gas	air	hydrogen
density [kg/m^3]	1.23	0.089
viscosity [Pa*s]	1.81E-05	8.40E-06
diameter of measuring channel* [m]	0.01	0.01
capacity of the meter** [m^3/h]	18	18
speed [m/s]	63.7	63.7
Reynolds number Re [-]	**43262**	**6748**
0.2* meter capacity [m^3/h]	3.6	3.6
speed [m/s]	12.7	12.7
Reynolds number Re [-]	**8652**	**1350**

*At present, hydrogen meters are unknown to network operators. Value is derived from current US meters.

** Here, three times the capacity of a G4 gas meter has been taken into account because a generally applicable capacity classification for hydrogen meters is not yet known. In doing so, the overcapacity that gas meters generally have has been applied.

Table 4 shows that the two flow cases for air and hydrogen have very different Re. So the flows are not comparable. The following conclusions can be drawn:

- At Q_{max} the flow with air is turbulent, and in most cases with hydrogen, too;
- At $0.2*Q_{max}$ the flow with air is typically, but not necessarily, turbulent; with hydrogen, it is always laminar.

The correct measurement of the gas flow rate therefore depends on the correct choice of the velocity distribution. This choice is important for low flow rates through the meter. When selecting ultrasonic or thermal mass flow meters, the network operators can ask the suppliers to what extent the meter's software is capable of making the right choice between laminar and turbulent flow, both with hydrogen and with air.

The flow resistance in a gas meter is determined by the density and the velocity squared. The pressure in a domestic gas meter cannot be changed, so it cannot be used to set the density of the gas.

Table 4 shows that the density of hydrogen is 13.8 times lower than that of air. The pressure difference across the meter is proportionally lower with hydrogen than with an equal amount of air flowing through. For mass meters, the difference in density will have no effect on the indication, but it will for bellows meters and ultrasonic meters because of the changed pressure difference over the meter.

A gas meter has a gas filter on the inlet side and a right angle in the outlet channel. For calculating the flow resistance in these situations, methods were found in reference literature for situations with $Re>10^5$. These methods cannot be used in a small consumer gas meter because the gas velocity is too low. The flow resistance of a hydrogen meter when flowing with air and hydrogen will have to be examined through experimentation.

Within CEN/TC 237, an inventory [1] of adjustments to existing gas metering standards for hydrogen was created in 2020. One of the clauses under consideration is the permissible pressure difference over the gas meter. It was concluded that with hydrogen, the current requirement (for natural gas, up to G16) of 2 mbar can be easily met. However, there is no specific requirement for the pressure difference with the control medium air. If the hydrogen meter is purged with air, the maximum expected pressure difference is 2*13.8= 27.6 mbar. Bellows and ultrasonic meters used in the Netherlands do not correct for such a large pressure difference.

It is not yet decided within CEN/TC 237 whether the pressure drop requirement for hydrogen will be tightened or whether the requirement for natural gas will be adopted. In the Netherlands, smart meters are equipped with temperature correction as standard, but not pressure correction. The range of the pressure measurement in the control installation must be sufficient to measure the pressure difference while the air is flowing.

3.3 Survey of meter suppliers

In 2021, five suppliers of gas meters were asked about the status of their development of hydrogen meters and about the time frame within which they expect to be able to supply hydrogen meters to Dutch network operators. The questions were prepared by Netbeheer Nederland and Kiwa Technology.

The results of the call for tenders have been summarised in the matrix in Table 1.

Table 5 Results of the informational survey among five meter suppliers

supplier	1	2	3	4	5
Measurement principle	Thermal mass flow	Ultrasonic	Ultrasonic	Bellows	Bellows
Types of gas	A separate meter for hydrogen	Current natural gas US meter adaptable for hydrogen	can measure both natural gas and hydrogen. Automatic changeover	all types because the volume is measured	all types because the volume is measured
implementation within NL meter chain	Functionality must be developed	Available	Functionality still under development	Available. Possibly new hardware design for the Netherlands	Current module can be used
Connections and capacities	NL 220 mm not in portfolio. Current bandwidth is up to G25.	NL 220 mm in portfolio; only for US up to G6.	NL 220 mm not in portfolio.	NL 220 mm is already in portfolio and can therefore in principle offer up to G25 for the KV meter.	NL 220 mm is already in portfolio and can therefore in principle offer up to G25 for the KV meter.
Test gases	Based on ISO 14687	Based on ISO 14687	Based on ISO 14687	In cooperation with NoBos	no information
Checking the meter with air	correlation between air and hydrogen is known	correlation between air and hydrogen is being investigated	correlation between air and hydrogen is being investigated	correlation between air and hydrogen is being investigated	No problem for bellows meter
Metrology and applicability	For households up to $20m^3/h$. For commercial use up to $120m^3/h$	Planned up to $30m^3/h$.	Focus on small consumption up to $20m^3/h$.	No information	Focus is on $20m^3/h$ for hydrogen
Risk if used incorrectly	it is possible that the meter is not working properly	No increased safety risk	No increased safety risk	No increased safety risk	No increased safety risk
Material suitable for hydrogen	Components not completely known have been identified	No problem	No problem	Material selected for its suitability	Material not yet selected for suitability
Safety	leakage test with 100% hydrogen prior to approval	ATEX classification must change from 2B to 2C	Mixtures with > 20% hydrogen requires ATEX amendment	ATEX modification necessary	No information
Availability	Q2/3 2022 meters available for Hy4Heat	Q2/3 2023	Expected MID acceptance Q4-2021, prototypes Q2/3 2022	Unknown	Unknown

In addition to the impression gained from the interviews and the filtering of competition sensitive information, the evaluation per topic from Table 5 is as follows:

- Measurement principle: speedometers 1, 2 and 3 are preferred to volume meters because of their compact design.
- Gas types: automatic switching between natural gas and hydrogen is of interest.
- Implementation within the meter chain: incomplete functionality can require a long development process.
- Connections and capacities: the speedometers will need an adapter as the 220 mm centre distance is not available; the volume meters do not need an adapter. The capacity is not a problem.
- Test gases: meters admitted with hydrogen including permissible impurities according to ISO 14687 are preferred.
- Control of meters with air: here the suppliers have uniformly low scores. It is worth noting that the knowledge of the persons interviewed on this subject was too limited.
- Metrology and applicability: the suppliers with more bandwidth scored higher.
- Risk if used incorrectly: based on the answers, no distinction was made.
- Material suitable for hydrogen: supplier 5 scored lower than the other suppliers here.
- Safety: There is sufficient knowledge of the need to change the ATEX classification for the meter and there is no distinction in this point as a result.
- Availability: suppliers 1 and 2 scored the best here by far.

Based on the above, the network operators have concluded that meter suppliers 1, 2 and 3 offer the most potential for supplying hydrogen meters in the short term.

4. Implementation process for traceable inspections

Traceable inspections for gas meters are implemented by distribution network operators during incoming goods checks and during random checks of meters in the field. Checks are also carried out on so-called problem meters, the status of which the connected party does not trust. The procedures for these checks are described in the Meter Pool KV Regulations and the documents referring to the Regulations.

In the following section, twelve phases have been identified for the implementation process. This includes an inventory of the points that need to be expanded as well as a proposal for expansion for each point. They are intended to be coordinated and worked out with the relevant representatives of Netbeheer Nederland.

4.1 Twelve phases for implementation in the Meter Pool KV

The twelve phases are shown in the following Table 6.

Table 6 Stages for the integration of hydrogen meters into the KV Meter Pool

Phase	Task
1	Expanding the KV Metering Regulations [2] to hydrogen meters.
2	Consulting with the supervisory authority, the Radiocommunications Agency Netherlands, concerning the extended regulations resulting in their potential application.
3	Expanding the implementing provisions [3] and Work Instruction 3 [4] to include hydrogen meters.

Phase	Task
4	Implementing the procedure for requesting a meter code for hydrogen meters from hydrogen meter suppliers.
5	Implementing the procedure for checking the hydrogen meters at the monitoring companies (Liander IJklaboratorium and CIJ Borculo).
6	Integrating the meter pool results from the hydrogen meters into the coordinator's meter pool reports.
7	Integrating the hydrogen topics into the technical audits for gas and the administrative audits from the coordinator.
8	Admission of existing or new control installations capable of measuring hydrogen meters by the coordinator.
9	Admission of meter auditors and authorised inspectors for checking hydrogen meters by the coordinator.
10	Implementing a calibration procedure with VSL for periodically calibrating the control installations that have been approved for hydrogen meters.
11	Expanding the monitoring results and inventory files to be sent periodically with data from hydrogen meters.
12	Expanding the coordinator's front office (MPS++) and back office (GMS) with the hydrogen meter functions.

The work in the phases is described below. References to paragraphs in the documents of the KV Metering Regulations are shown in black with square brackets to make a distinction. References are given at the beginning of the paragraph for quick reference.

4.1.1 Expanding the KV Metering Regulations to include hydrogen meters

[3.1.2] The properties table for gas meters is based on one unspecified gas. The properties table has been expanded to show a letter indicating the gas flowing through the meter. “G” now stands for natural gas. A new letter will be introduced for hydrogen meters that is understandable for meter auditors, preferably “W” for the Dutch term “Waterstofmeter”.

[4.1.3] For gas meters that automatically switch between natural gas and hydrogen, the network operator will report which gas is flowing through the meter to the coordinator prior to organising the random check.

[11.1.1] After the gas flowing through a switchable gas meter has changed from natural gas to hydrogen, a new check should preferably not be performed for this lot. A condition for this is that the meters are only present in the grid for a short time during the transitioning period to hydrogen.

4.1.2 Consulting with the supervisory authority, the Radiocommunications Agency Netherlands, concerning the extended regulations

Within the framework of this project, consultations were held with the Radiocommunications Agency Netherlands. In the event of an amendment to the KV Metering Regulations, the new regulations will be submitted to the Radiocommunications Agency Netherlands before they enter into force.

4.1.3 Expanding the implementing provisions and work instructions to include hydrogen meters.

Work instruction 3 - Performing control measurements [4]
[2] Scope. The scope now includes bellows and ultrasonic gas meters. Thermal mass flow meters will be installed in the future, bringing them into the scope.

[5.1.2.3] The meter data verified by the meter auditor will be extended with the type of gas for which the meter is designed: natural gas or hydrogen, or both gases if the meter is suitable for both gases. Making a distinction between meter codes using the first letter can be of great help here: G (natural gas), W (hydrogen gas, Dutch: Waterstofgas), H (hybrid: hydrogen or natural gas). The two-gas meter will be checked for the gas present in the network at the time of the check.

Work instruction 3 assumes that the test installation is suitable for carrying out the control measurements. This means that the hydrogen test facility still needs to be designed and built. The requirements for test installations are discussed further in Table 12.

Work instruction 5 Reporting and managing control installations [5]
[2] The scope refers to control installations for gas meters. This will be extended to natural gas and hydrogen meters. The types of meters being monitored will be expanded to include ultrasonic and thermal mass flow meters for hydrogen.

The upper limit of the volume flow of gas in hydrogen meters for small consumers has not yet been set by the Ministry of Economic Affairs and Climate Policy. Based on the ratio of the energy content of hydrogen and natural gas, the required capacity of the test installation is approximately 120 m^3 per hour. After it is established, the upper limit for hydrogen will be included in the work instruction. The control installation may only be used for hydrogen meter checks by meter auditors who are competent in inspecting hydrogen meters.

[5.2.1] Notification of the installation to the coordinator of the Meter Pool KV
The notification form will mention hydrogen if the control installation is designed for this purpose.

Implementing provisions [3]
[3.2.1] The meter lots to be monitored in a year are predefined by the coordinator of the Meter Pool. Varying the frequency of checks is permitted. Due to the novelty of the hydrogen meters, network operators have to determine whether a modified frequency of checks for these meters is applicable. It is important to monitor hydrogen meters closely, and based on the results of the manufacturer's initial inspection data, it may be decided to carry out an additional inspection in a given year.

[4.2.1] The network operator records the type of gas flowing through the meter in its meter register; in this case hydrogen.

[4.2.1.1] The meter code consists of a letter and four digits. For hydrogen meters the letter "W" applies.

In the case of a meter that can be switched between natural gas and hydrogen, we are dealing with two different measuring instruments in one housing. The difference is in the capacity of the meters, which is three times higher for hydrogen. On the index of a switchable meter, both a “W” and a “G” meter code are marked.

The switchable meter currently under development is an ultrasonic meter that can detect the type of gas based on the speed of sound of the gas. If the network operator changes the type of gas in the network, the meter adjusts automatically. The meter code valid during the periodic inspection of a switchable meter will be specified by the network operator.

[4.2.1.5] Additional properties may be required for hydrogen meters, which are not known at present. These can be added to the properties table after consulting with the Radiocommunications Agency Netherlands.

[4.2.3.4] If a meter supplier submits an application to the coordinator for a hydrogen meter code, the assessment procedure will be expanded to include an examination of the possibility of controlling the meter with air. An important part of this research is the metrological rejection limits of the meter and the gas flow rates at which the meter is checked with air. These data are reported by the coordinator to the company performing the checks.

[4.6.2.1.1] Notifications to the coordinator for a control installation will state that the installation is suitable for monitoring hydrogen meters. During the assessment of the control installation, the coordinator checks several hydrogen meters for the evaluation.

A monitoring company can test the control installations in the interim with one or more reference gas meters, the so-called *Golden Samples*. These do not yet exist for hydrogen meters. If desired, they may be applied.

[4.7.1] The control criteria are identical for bellows gas meters, ultrasonic meters and thermal mass flow meters, irrespective of the gas type.

[4.7.2.2] No information has been provided at the present on the specific requirements for each meter type. Should it become apparent in the future that specific requirements apply to ultrasonic and thermal mass flow meters for hydrogen, they will be listed here.

[4.7.3.1] The rejection criteria for hydrogen meters follow from the class of the meter and whether there is compensation for the temperature. The network operator determines these two aspects when drawing up the specifications that the hydrogen meters must meet.

[4.7.3.4.1] The purge volume for ultrasonic and thermal mass flow meters for hydrogen, with which the meters are flushed prior to a metrological control, has been calculated with linear scaling from the values applicable to natural gas meters. The scale factor is equal to the ratio of the energy content of natural gas and hydrogen, i.e. three.

The purge volume for ultrasonic and thermal mass flow meters for hydrogen shall be at least 300 litres at Q_{max}=18 m^3/h and 750 liters at Q_{max}=30 m^3/h.

The implementing provisions are based on ultrasonic meters up to Q_{max}=10 m^3/h for natural gas. Larger meters are not currently described in the implementing provisions.

[4.7.3.2.4] The metering time for a metrological control is determined for the Meter Pool KV based on the minimum metering volume and the minimum metering time.

The starting points are the reading accuracy and the rejection limit of the meter. The rejection limit of a class 1.5 meter in the field is twice the permissible deviation of 1.5%, i.e. 3%.

The minimum volume to be passed according to the implementing provisions is indicated in Table 7.

Table 7 Minimum volume to be passed for meters with 3% rejection limit

Meter type	Readout accuracy = 0.1 dm^3	Readout accuracy = 1 dm^3
Speedometer with 3% rejection limit	43 dm^3	425 dm^3

In Table 8, the measurement time for hydrogen meters is indicated in case of a reading accuracy of 0.1 dm^3 and 1 dm^3.

Table 8 Measuring time for ultrasonic and thermal mass flow meters for hydrogen

Q_{max}	Readout accuracy	test	flow rate	minimum volume to be passed through	measuring time
dm^3/h	dm^3		dm^3/h	dm^3	min
18000	0.1	Q_{max}	18000	900	3
18000	0.1	0.2* Q_{max}	3600	180	3
30000	0.1	Q_{max}	30000	1500	3
30000	0.1	0.2* Q_{max}	6000	300	3
18000	1	Q_{max}	18000	900	3
18000	1	0.2* Q_{max}	3600	425	7.5
30000	1	Q_{max}	30000	1500	3
30000	1	0.2* Q_{max}	6000	425	4.5

In Table 8, it appears that hydrogen meters with a reading accuracy of 1 dm^3 need a longer measuring time at the measuring point 0.2*Q_{max}. A logical request from the network operators for hydrogen meter properties is a reading accuracy of 0.1 dm^3.

[4.7.4] The requirements for hydrogen meter control installations are the same as those for current natural gas meter control installations, except for capacity. This will be expanded to the limit for small consumer meters. The control installation with a capacity of 120 m^3/h has yet to be designed and built. If the hydrogen meters can be tested with air, it makes sense in the short term to check hydrogen meters for small consumers with a control installation that can only go through the test procedure for hydrogen meters using a software adaptation. The current control installations have a capacity of 40 m^3/h, which makes hydrogen meters the same as G4 and G6 for natural gas, which can control up to 30 m^3/h.

[4.7.4.9] The software for control installations will be expanded to include control procedures for checking hydrogen meters. The flow rates and measuring times specified in Table 8 are set when the meter code of the corresponding hydrogen meter is called up.

[4.7.4.11] At the present, the implementing provisions do not lay down specific requirements for the control installations for each type of gas meter. For controlling hydrogen meters with air, a higher pressure loss over the meter with air should be taken into account than is the case with hydrogen in practice. The reason is that the density of air is 13.8 times higher than that of hydrogen. At the same flow rate through the meter, the pressure drop becomes 13.8 times higher with air. The pressure measurement in the control installations must be calibrated to the expected pressure interval.

At present, the pressure drop over gas meters is determined by the provision in the (EU) standards. However, it is not a rejection criterion in the Meter Pool KV.

[4.9] The statistical analysis of the control results is the same for hydrogen meters as for other meters in the Meter Pool KV. In the annual reports of the coordinator, the gas meters are characterised using the lot, the meter code, the year of construction and the Q_{max} of the meter in m^3/h. Hydrogen meters are characterised in the same way and can be included in the same tables as gas meters. Hydrogen meters can be added to the annual reports without substantive changes.

[4.11.2] The network operator keeps an inventory file of its meters. Hydrogen meters can be recognised in this file by the meter code starting with "W". Meters that automatically switch between natural gas and hydrogen should be changed accordingly in the inventory file.

[4.11.6] The data from the meters as they come off the production line at the manufacturer ("first inspection" data) will be requested by the coordinator. When purchasing the meters, it is recommended for the network operator to include the coordinator's request in the order.

[B5.2] The initial letters of the meter code in the defect register will be expanded with "W" for hydrogen meters.

4.1.4 Implementing the procedure for requesting a meter code for hydrogen meters from hydrogen meter suppliers

The procedure for requesting hydrogen meters contains new elements:

- The type of gas for which the meter is intended. Until now, there was no indication for the type of gas, but this information is being introduced now through a new data field. The gas type is known in advance. A possible characterisation in the data field is G for natural gas and W for hydrogen. In practice, the type of gas determines the control procedure to be followed. The hydrogen meter must indicate hydrogen as the type of gas. It is expected that this can be done with a reference to ISO-16487.
- The rejection limits of the hydrogen meter in the metrological control using air. These rejection limits are determined by the designated authority or notified body (Nobo). In contrast to the rejection limits with hydrogen, the rejection limits with air for the two measuring points 0.2 x Q_{max} and Q_{max} can differ. The upper and lower limits may be asymmetrical with respect to the zero line.

The translation of the behaviour of the meter with hydrogen to control with air follows from a comparative measurement of a number of meters with both hydrogen and air. This data is provided by the notified body that issues the meter approval. At the moment, it is not yet known which information will be supplied, but it should at least consist of the values contained in Table 9.

Table 9 Rejection limits with control using air

Measuring point	$0.2 \times Q_{max}$	Q_{max}
Lower rejection limit	$MPE_{0.2xQmax; low}$	$MPE_{Qmax; low}$
Upper rejection limit	$MPE_{0.2xQmax; high}$	$MPE_{Qmax; high}$

MPE=maximum permissible error

4.1.5 Implementing the procedure for checking the hydrogen meters

Within the KV Meter Pool, two companies perform random checks on gas meters. These are the Liander IJklaboratorium and CIJ Borculo.

Within the context of CEN/TC 237[3], it is being assumed for the time being that testing hydrogen meters for small consumers will be performed using air.

For Meter Pool KV, the deviation of a gas meter is determined based on the flow rates $0.2 \times Q_{max}$ and Q_{max}. Currently, the permissible deviation of a gas meter is determined by its accuracy class. When checking meters in the field, the class of the meter is known from the meter register of the network operator and the automatic assessment of the meter is based on this.

If the behaviour with air differs from with hydrogen, then translation to the behaviour with air applies rather than the accuracy class. The translation for the behaviour of a gas meter with hydrogen to the behaviour with air is not yet known.

The relationship between hydrogen and air depends on the measurement principle[4], the model of the meter and the adjustment of the meter applied by the supplier in production. The Dutch network operators assign a meter code to a gas meter, which is based on the approval and model of the meter. For every year that meters of a certain meter code are produced, Netbeheer Nederland carries out a five year random check. It is therefore to be expected that for each combination of meter code and year of construction, a specific link should be established for the control using air.

The service life requirement for gas meters is usually 15 or 20 years. The battery capacity in modern meters is based on this period of service life. Recent research[5] shows that battery capacity can influence the replacement strategy for smart gas meters. Assuming a 15 year service life and the current data collection of the Meter Pool KV, the control scheme in Table 10 can be adopted.

[3] CEN/T 237 standards committee “Gas meters”; chairman’s statement.
[4] EURAMET project NEWGASMET
[5] Rijpkema, residual capacity batteries, Kiwa Technology commissioned by Netbeheer Nederland

Table 10 Data collection times for the Meter Pool KV

Time in the service life of a hydrogen meter	Statistical data	Origin of the data
Upon purchase	First test data	Manufacturer
After one year	Deviation after one year	Voluntary by the network operator
After five years	Deviation, five year check	Network operator, under the control of the regulator
After ten years	Deviation, five year check	Network operator, under the control of the regulator
Prior to fifteen years	n/a	During this period, the meter may be replaced[6].

Table 10 shows that a lot of hydrogen meters is statistically checked at least three times during their operational service life. With a 20-year service life, this means four times.

Hydrogen meter approvals will only mention matters that pertain to the medium for which the meter is approved. There is therefore no need to include information on behaviour with air in the approval[7]. The network operator will have to request this information from the supplier or have it recorded by an appropriate party.

The translation will have to be built into the software of the control installations. Currently, the control procedure is automatically adapted to the meter being checked based on the meter code. The same principle can be used for hydrogen meters. After entering the meter code, the following parameters are set:

- The flow rate of the test ($0.2 * Q_{max}$ or Q_{max})
- The permissible deviation. In the field, this is twice the requirement of the MID; for class 1.5 meters, a permissible deviation of +/- 3% applies.
- The flow rate through the meter during the test.

By consulting a table in the software, the correct data for the test are automatically set by the control installation.

If a meter is rejected in the field based on an impermissible deviation, further testing of this meter is required[8]. In the case of a hydrogen meter, this further testing of the deviation will have to be carried out using hydrogen as the medium in order to prevent any effects of discrepancies resulting from the translation to air. The results of the test using hydrogen therefore prevail over the results of the test using air. In the case of testing with hydrogen, the permissible deviations according to the class of the meter apply. It may be that a hydrogen meter is metrologically approved at a second stage. This may have important implications for the assessment of the associated lot in the field. The further testing must therefore be carried out in good time before the annual decision on lot acceptability is made by the coordinator.

The benefits of a hydrogen calibration facility can be described as follows:

- Research into hydrogen meters takes place in the Netherlands, thereby increasing knowledge about gas quantity measurement

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[6] It is assumed that replacing the entire meter is preferable to replacing only the battery.
[7] Information from Henri Schouten, NMi, May 2021
[8] See the *Meter Park Management Regulations* of Netbeheer Nederland.

- Confidence in quantity measurement of hydrogen is strengthened
- In the event of a dispute between the connected party and the network operator about the meter reading, a quick and well-founded additional check of the meter can be carried out using hydrogen

It is expected that as the use of hydrogen increases, the demand for such a facility will become more urgent.

4.1.6 Integrating the meter pool results from the hydrogen meters into the coordinator's meter pool reports

The quality of gas meters and kWh meters is reported separately by the coordinator of the KV Meter Pool. Reporting is on an annual basis. The quality of the hydrogen meters is included in the decision on lot acceptability and the lot recommendations for the gas meters.

The lots of hydrogen meters are described using a combination of the meter code and the year of construction. The meter code indicates that it is a hydrogen meter. This is sufficient to distinguish it from ordinary gas meters. In the reports, the capacity of gas meters is indicated in m^3/h; the hydrogen meters can be included in this system.

4.1.7 Integrating the hydrogen topics into the audits from the coordinator.

Technical gas audits

The technical audits cover the checks of the hydrogen meters in the field and the competence level of the meter auditors. The main focus of the audit is to ensure that the control is carried out properly.

A mobile test installation (MTI) responds to the input of a meter code by displaying the test parameters to the meter auditor. These are the flow rates to be set during the test and the rejection limits against which the counter readings are compared. When a hydrogen meter is tested, different flow rates apply than are usually used for natural gas meters. The software makes its selection from a separate table of flow rates that are applicable to hydrogen meters. The metrological rejection limits are the same as those for gas meters specified in the MID.

The pressure difference over the gas meter during the Q_{max} test is recorded by the installation, but is not a reason for rejection within the Meter Pool KV. Since air is used during the test, a higher pressure difference is to be expected than that stated in the EN standards for gas meters.

A conventional calibration table with a wet gas meter cannot be increased in capacity. The scope of this kind of control installation cannot be expanded. For the sonic nozzle stationary calibration installations at Liander, the range of nozzles present must be expanded to include ones that can deliver the increased flow rate.

Administrative gas audits

The administrative gas audits are carried out by the coordinator at the network operator. The meter pool system provides the coordinator with information on which he or she can expand the audit with the network operator:

- Application of a "W" meter code in advance.
- The receipt of a test sample of the hydrogen meter for evaluation
- The control installations on which checking the water meter is permitted
- The results of the plausibility check of MPS++

- The results of the metrological control
- The results of the statistical analysis of the meters in a lot
- The data of the first inspection.

The coordinator usually selects the critical meter code/building year combinations in the current monitoring year. When a lot of hydrogen meters arrives, it makes sense to closely monitor the quality of the administrative process of these meters.

4.1.8 Admission of existing or new control installations capable of measuring hydrogen meters.

The approval procedure described in Work Instruction 5 is sufficiently general to permit new hydrogen meter control installations. At 40 m^3/h, the capacity of the installations is now equal to the limit between large and small consumer gas meters. The limit should be raised to the upper limit for small consumer hydrogen meters, approximately 120 m^3/h. The definition of the exact limit flow rate is the responsibility of the Minister of Economic Affairs and Climate Policy. The service providers working for the Meter Pool KV do not have control installations with increased capacity for hydrogen meters. Perhaps an MTI for large-scale consumption from CIJ Borculo could be allowed for the Meter Pool KV.

4.1.9 Admission of meter auditors and authorised inspectors for checking hydrogen meters.

Meter auditors

The meter auditors of CIJ Borculo go through an internal competence test before they can be admitted to the Meter Pool KV. This internal examination is extended to include the inspection of hydrogen meters using a mobile test installation. With an initial audit by the coordinator, the meter auditor is admitted to the Meter Pool KV. This first audit will be expanded to include hydrogen meter inspections.

If a meter auditor has already been admitted to the Meter Pool KV, an additional audit only for hydrogen meters is sufficient to allow the meter auditor to work with hydrogen meters.

Authorised inspectors

The Liander IJklab calibration laboratory employs authorised inspectors who are audited by the Netherlands Metrology Institute (NMi). In addition to the metrological controls, they also have the authority to assess meters.

The requirements for admission to the Meter Pool KV are identical to those of the meter auditors from CIJ Borculo. Authorisation follows demonstration of the control procedures. Liander works with sonic nozzle calibration benches. An overview of the authorised inspectors and control installations can be found in Table 11.

Table 11 The type of calibration benches and authorisation of meter auditors at the monitoring companies

Monitoring company	Liander IJklab	CIJ Borculo
Technical management	does not carry out checks	authorised inspector
Meter auditors	authorised inspector (policy)	not necessarily authorised
calibration bench with volume meter	no	yes
sonic nozzle calibration bench	yes	no
mobile testing installation	no	yes

The installations are not equipped for hydrogen meters. The installations have to be changed before hydrogen meters can be checked.

4.1.10 Implementing a calibration procedure for hydrogen meters with VSL for periodically calibrating the control installations that have been approved for hydrogen meters.

If it is possible to check hydrogen meters with air, the Meter Pool KV control installations can be calibrated with VSL reference meters. The capacity of the reference meter must be suitable for the higher flow rates of the hydrogen meters.

4.1.11 Expanding the monitoring results and inventory files to be sent periodically with data from hydrogen meters.

The format in which the control results are sent to the coordinator by the participating network operators is sufficiently general to be used for hydrogen meters. The meter code used for hydrogen meters (Dutch: Waterstofmeter) starts with the letter “W” and is possible within the alphanumeric format applied.

At the moment, it is not yet known how the capacity of hydrogen meters will be designated at the European level. If the indication will change significantly from the current G-value, the format of the control results will have to be adjusted.

4.1.12 Expanding the coordinator’s front office (MPS++) and back office (GMS) with the hydrogen meter functions.

The data uploaded by the network operator goes through a plausibility check in MPS++. The information from hydrogen meters should not be characterised as incorrect. The following amendments are necessary:

- The letter “W” is becoming an accepted designation for the gas type.
- The capacity indication of the meter is defined in MPS++ and the data is compared with it.

4.2 Specification of a calibration installation for hydrogen meters

The considerable difference in gas properties makes traceable calibration of a hydrogen meter using hydrogen the preferred medium. Calibration installations using hydrogen are not available in the Netherlands. The German metrology institute Physikalische Technische Bundesanstalt (PTB) [6] is developing such a facility. The Netherlands Metrology Institute (NMi) is a designated body for the approval of gas meters according to the Measurement Instrument Directive (MID). It uses a calibration installation in Glasgow (Scotland).

Within the framework of this project, consultations were held with the Van Swinden Laboratory (VSL) in Delft regarding the possibilities of developing such an installation for the Netherlands. It was found that a programme of requirements for the installation creates a high degree of clarity for defining a project. The requirements in Table 12 have been drawn up in response to the 2021 consultation between Netbeheer Nederland, Kiwa Technology and VSL.

Table 12 Requirements for a calibration facility for hydrogen meters

No.	requirement	values	Source / comments
1	medium	Hydrogen or air/nitrogen	The difference in the behaviour a gas meter demonstrates when using hydrogen and air must be established.
2	Types of meters	Ultrasonic and thermal	These are preferred due to their compact dimensions
		Bellows	Measuring this type of meter is desirable.
3	Capacity	Values in m^3/h	EN 1359; Table 1: flow rates of G4 and G6 natural gas meters. EN 14236; Table 2: Class 1.5 meters. Multiplied by a factor of 3 for the ratio of energy content.
	Minimum	<= 0.12	Based on Q_{max}/Q_{min} >= 150
	Maximum	40	CEN/TC 237: proposal for a new standard for ultrasonic gas meters
	Measurement points (H_2 equivalent of natural gas)	3.6	Meter pool KV: 0.2 x Q_{max} of G4
		18	Meter pool KV: Q_{max} of G4
		6	Meter pool KV: 0.2 x Q_{max} of G6
		30	Meter pool KV: Q_{max} of G6
4	Contaminants in hydrogen	Test gas contains >99.9% hydrogen	Bottled gas hydrogen specifications 3.0
			Meters from the network should be rinsed before conducting the test.
		Nitrogen, controlled proportion up to 3%	Netbeheer NL, Study of hydrogen specifications
	Contaminants in air	Ambient air	Common in the Netherlands
5	Uncertainty of gas quantity	<= 0.33%	Similar to the uncertainty of the current VSL travel standard for calibrating control installations for gas meters

No.	requirement	values	Source / comments
6	Pressure[9] (negative pressure system)	Sufficiently low to achieve the required capacity	Without influencing the behaviour of the meter
	Pressure (positive pressure system)	Minimum 20 mbar positive pressure	5 mbar lower than the setting of domestic pressure regulators in EN
		Maximum 100 mbar positive pressure	Distribution pressure of natural gas
7	Temperature	Laboratory temperature: 22 °C with a discrepancy of max 5 K close to the test set-up;	PTB testing instructions; Band 29; Measuring instruments for gas (Table 5)
		variation over 24 hours <2 K;	
		variation during the test for temperature-corrected meters <0.3 K	
		Temperature gradient per altimeter in the space: <0.5 K	

These requirements provide guidance for the development of a calibration facility.

The flow rates mentioned in Table 12 apply to hydrogen meters equivalent to G4 and G6 natural gas meters. The scope of the current Meter Pool KV is up to G25. A hydrogen meter equivalent to G25 requires a hydrogen capacity of 120 m^3/h. Ultimately, this test flow rate is necessary for hydrogen. This may play a role in the choice of the technical solution. Two possible technical configurations are described in [7]:

Circuits with bottled gas

The gas meter is mounted in a closed circuit, which is filled with bottled hydrogen. A compressor provides the necessary gas flow in the circuit. To keep the temperature of the gas constant, a heat exchanger is placed after the compressor that is used to heat the gas.

The advantage of this solution is the low gas consumption. However, regulating the amount of gas is complex and the circuit contains expensive components.

Open outflow with bottled gas

The gas meter is placed in a pipe where the pressure of the bottles drives a flow of hydrogen. After the hydrogen has flowed through the meter, it is mixed with air and burned.

This is a simple technical set-up, but one that consumes a lot of hydrogen. The temperature increase of the hydrogen due to expansion must be taken into account.

The TÜV-SÜD [8] has built a test set-up for domestic gas meters in Glasgow that allows the meter to be flushed with hydrogen and percentages of other gas types. Hydrogen of distribution quality, which can contain a small percentage of nitrogen or methane, can be generated with this set-up.

The mixed gas flow is controlled by the pressure difference via nozzles. Each gas component has a number of switchable nozzles. This kind of method for regulating the gas flow is also used in the sonic nozzle calibration benches at Liander in Apeldoorn. It is an open set-up type with an outflow of

[9] Whether the measurement is to be carried out using positive pressure or negative pressure has not yet been determined.

bottled gas [9]. The hydrogen is vented into the outside air preventing the flow resistance downstream of the nozzles from affecting the measurement. The uncertainty of the Glasgow set-up is mentioned in Table 13.

Table 13 The uncertainty of the TÜV-SÜD set-up in Glasgow.

Component	Uncertainty	k-value*
Hydrogen	+/- 0.3%	2
Nitrogen	+/- 0.2%	2
Methane	+/- 0.5%	2

*The k-value of 2 means that the uncertainty interval has the width of 4 times the standard discrepancy (+/- 2 times).

The uncertainty of a mixture consisting of hydrogen and another gas is derived from the square root of the sum of the uncertainties, multiplied by their share of the gas flow.

For example with the values from Table 13: a mixture consisting of 98% hydrogen and 2% methane has an uncertainty of 0.31%. See Table 14.

Table 14 Combined uncertainty for hydrogen and methane

hydrogen concentration	**a**	**98%**
uncertainty with hydrogen	b	0.30%
concentration of methane	c	2%
uncertainty with methane	d	0.50%
a x (b)^2	e	0.00000882
c x (d)^2	f	0.0000005
root (e + f)		0.31%

This value falls within the requirement set in Table 12. However, at higher methane contents, the uncertainty increases and may exceed the requirement. When nitrogen is added, the uncertainty decreases.

5. Result

A preference for measurement principles has been expressed for the measurement of hydrogen with small consumers. The reason for the preference is described and allows for an informed decision between current products and suppliers. It is to be expected that a wider range of hydrogen meters will also lead to a greater choice of measurement principles.

The differences between the flow of hydrogen and air in a gas meter are described. This knowledge allows network operators to define targeted experiments to evaluate the accuracy of a hydrogen meter.

With the proposals for expanding the text in the Meter Pool KV documents, the participants can easily expand the regulations, the implementing provisions and the work instructions to include hydrogen. The control installations for measuring hydrogen meters are described.

The social benefits of using a calibration facility for hydrogen meters has been described and a technical set of requirements for such a facility has been drawn up. It is up to interested parties to decide on the development of this facility.

6. Conclusions

The statement from various meter suppliers that their ultrasonic or thermal hydrogen meters can be checked using air cannot be verified at the present by meter users.

Due to the considerable differences between the physical properties of hydrogen and air, assuming that an ultrasonic or thermal hydrogen meter can be checked with sufficient accuracy using air is not a logical conclusion. Further information on this will be received from the designated body responsible for evaluating hydrogen meters for European authorisation.

Tests with hydrogen and air can only be carried out once a meter has been made available. Meters become available after a notified body has issued an MID approval for a meter.

For the M&VH2 project from Netbeheer Nederland, which expects to have approved hydrogen meters available for field installation by the end of 2024, there is still sufficient preparation time to have the meters ready in time. Despite statements from meter suppliers that approved hydrogen meters can be delivered by the end of 2021 or the beginning of 2022, it is not entirely certain at the present whether hydrogen pilot projects with small consumers that are planned to start in the near future will have approved meters available in time.

Amendments to the KV Metering Regulations for the purpose of integrating hydrogen meters, to the underlying implementing provisions and to the work instructions can be created based on the information contained in this report.

A calibration facility with hydrogen is required in order to assess the behaviour of a hydrogen meter using hydrogen gas in a way that is traceable. A specification for calibration facilities for hydrogen meters for small consumers has been prepared. This kind of facility already exists in Germany and in Scotland, but not in the Netherlands. The possibility of having a hydrogen meter assessed domestically using hydrogen will increase consumer confidence in the new meters and hydrogen as an energy supply.

Gas network operators need the regulated domain and free domain to be separated for hydrogen meters in a way that is very similar to the method currently employed for natural gas meters.

7. Recommendations

Analyse the difference between the metrological behaviour of new hydrogen meters using hydrogen and using air.

Implement the applicable test parameters when air flow is used in a hydrogen meter into the software of gas meter control installations used in the Meter Pool KV.

Define alternative metering methods for the energy supplied in the form of hydrogen for pilot projects that can serve as a temporary replacement for hydrogen meters in case the permitted hydrogen meters become available later than the start of the energy supply.

Start a project under the direction of the Meter Pool KV operator in order to prepare and implement the necessary adjustments in the quality system depending on when the first hydrogen meters will be installed in the distribution network. Make the procedure for inspecting problem meters part of the project.

Strengthen the confidence of small consumers in hydrogen and hydrogen meters by making the meters traceable, as is already done for natural gas meters in the Netherlands. Develop a national hydrogen calibration facility for this purpose.

Design the calibration facility for hydrogen meters based on the set of requirements described in this report.

Define a hydrogen flow rate that separates the regulated domain from the free domain for hydrogen meters.

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Abbreviations

ATEX	EXplosive ATmospheres
CEN/TC	European Committee for Standardisation/Technical Committee
EN	European standard
G4, G6 and G25	Capacity indication of gas meters with 6, 10 and 40 m^3/h
GMS	Gas meter system
KV	Small consumers (Dutch: Kleinverbruik)
ISO	International Standardization Organization
NoBo	Notified body
MID	Measuring Instrument Directive
MPE	Maximum permissible error
MPS++	Meter pool system++
MTI	Mobile test installation
M&VH2	Measurements and calculations for hydrogen
US	Ultrasonic
Q_{max}	Maximum capacity of a gas meter

Appendix 1 WP 1D deliverable 1D1

As part of the project proposal for Work Package 1D - Gas quantity measurement, a topic was defined where recommendations would be defined on the practical composition of hydrogen in gas networks based on research in reference literature and interviews with experts.

During implementation of the WP 1D, it became clear that many steps had already been taken towards defining the hydrogen that will flow into gas networks in the Netherlands. The decision was then made not to pursue this topic further.

HyDelta has expressed the desire to include a summary of the results of the component in a brief report. This appendix contains the description of the reference literature that was reviewed. The scope of the investigation is not complete, as it concerns only three references, which proved sufficient in deciding to stop the work.

The following three sources were consulted.

ISO 16487 Hydrogen fuel quality – product specification (end of 2019)

This standard describes the type 1, grade A: gaseous hydrogen, intended for domestic and small commercial applications connected to a gas network, among others.

The standard describes the main components in the gas and permissible trace components (contaminants). The hydrogen meters covered in Sections 2 and 3 of Work Package 1D are products oriented towards the international hydrogen market. The suppliers have declared that these meters are suitable for hydrogen type 1, grade A.

Netbeheer Nederland – a study of hydrogen specifications (2020)

For the practical composition of hydrogen in Dutch networks, Netbeheer Nederland commissioned a study of the requirements for new hydrogen networks and existing natural gas networks. An overview of the compositions at entry and exit points of both networks was presented. The only aspect that has only been partially quantified is the odorant, as investigations into suitable odorants are still in progress. The general picture is that the compositions are very similar to hydrogen type 1, grade A in ISO 16487.

Hynetwork services – hydrogen quality specification

The company Hynetwork services develops transport infrastructure for hydrogen in the form of a high-pressure pipeline system between Groningen and various industrial locations in the Netherlands, the so-called Hydrogen Backbone. Various applications will be connected to the grid in the north of the Netherlands, the port of Rotterdam and, in the future, in the south of the Netherlands. The composition of the hydrogen in the transport network can be downloaded from the website. (https://www.hynetwork.nl/nieuws/kwaliteitsspecificatie-waterstof)The specification includes main components and trace elements. In contrast to the Netbeheer Nederland specification, the gas in the transport network is not odorised.