# HyDelta

## WP1B – Gasstations

D1B.1 – Operation of gas stations with spring loaded regulators with hydrogen

Status: final

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# Document summary

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**Dissimilation level**

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## Executive summary

The Dutch system operators (DSOs) are planning to examine if the existing – or slightly modified – gas pressure reducing and metering stations that are currently being applied for use with **natural gas**, will also be suitable for use with **hydrogen** ($H_2$).

At the moment, only limited knowledge is available about applying the current gas pressure reducing and metering stations for **natural gas** are suitable to operate with **hydrogen** to adequately, reliably and safely reduce pressure.

The goal of this research program focuses on the following key question: is an existing gas pressure reducing and metering station, operated with **natural gas** and equipped with a spring loaded safety valve, also suitable for **hydrogen**.

For the execution of the experimental program, a gas pressure reducing and metering station has been made available by Enexis on behalf of the DSOs. The design capacity of the station is 100 $m^3_n$/h (**natural gas**) (according to gAvilar specifications) with a minimum inlet pressure of 3 bar. The gas pressure reducing and metering station is in compliance with the NEN 1059: 2019.

Also, a high pressure delivery station (HAS) has been made available by RENDO on behalf of the DSOs. The design capacity of this station is about 30 $m^3_n$/h (**natural gas**) at 4 bar inlet pressure. This HAS is also in compliance with the NEN 1059: 2019.

The experimental program has been executed according to a test protocol which describes the different steps to be followed, the operational conditions and the circumstances of the specific measurements. The capacity of the safety valves exceed the capacity of the gas pressure reducing and metering station.

The gas pressure reducing and metering station was first tested with **natural gas** to a maximum flow of 200 $m^3_n$/h. The station was then tested with **hydrogen** to a maximum flow of 600 $m^3_n$/h. Other tests focusing on leak tightness and closing pressure were also executed according to the test protocol.

The high pressure delivery station (HAS) was first tested with **natural gas** to a maximum flow of 30 $m^3_n$/h. The test was then repeated with **hydrogen** to a maximum flow of 90$m^3_n$/h. Additional tests have also been executed here in accordance with the test protocol.

## Conclusion

Based on the experiments, the main conclusion of this report can be formulated as follows:

The gas pressure reducing and metering station, equipped with spring loaded safety valves and designed for **natural gas**, can be used to adequately, reliably and safely reduce the pressure for **hydrogen**. The tests with the different safety valves show only small differences between **natural gas** and **hydrogen** when comparing the results for the steps from the test protocol.

Comments:

- The conclusion of this research involves the technical functionality of a gas pressure reducing and metering station. The long-term effects on the components have not been tested in this test program and as such, no conclusions can be drawn on this specific matter.

# Table of contents

# 1. Introduction

## Reason

The Dutch regional system operators are planning to establish the suitability of existing – or slightly modified – gas pressure regulating stations for natural gas ($L_{gas}$ [1]) for use with pure [2] hydrogen ($H_2$).

## Problem definition

At the moment, there is only very limited information available as to whether current (natural) gas pressure regulating stations are technically suitable for reducing the pressure of hydrogen in an adequate, reliable and safe manner. Hydrogen has different physical properties to natural gas and in order to supply the same amount of energy as with natural gas, the flow rate of hydrogen needs to be three times higher at the same pressure [3]. It is necessary to check whether these factors have an effect on how the station performs on a technical level.

In 2020, Kiwa Technology tested a new (natural) gas pressure regulating station using hydrogen. This gas pressure regulating station (with gas-operated regulator and related components) was found to be suitable for use with hydrogen. See the report Kiwa - Gas pressure regulating station for hydrogen - Netbeheer Nederland - GT-200308, April 2021.

The main difference as compared to the HyDelta programme is that the (natural) gas pressure regulating station for the aforementioned research was equipped with a gas-operated regulator and had a much larger capacity.

## Objective

The objective of this research is to gain insight into the operation and suitability of a gas pressure regulating station if the medium of hydrogen is used instead of natural gas. Testing will be used to examine the following aspects:

- The external leak tightness of the gasstation as a whole when using hydrogen.
- Proper operation of the components when using hydrogen.
- The internal leak tightness of the valves and safety devices.
- Operation of the safety devices.
- Operation/ control behaviour of the various spring loaded regulators.

As explained above, in order to supply the same amount of energy as when using natural gas, the volumetric flow rate of the hydrogen in the gas network and therefore also in the gas pressure regulating stations needs to be higher. Based on the 2020 research, it is expected that this can be achieved with the same components and pressures. This research is intended to determine, by means of practical tests, the effects of increasing the volumetric throughput on the overall operation of the (natural) gas pressure regulating station.

[1] The $L_{gas}$ (low calorific gas) consists of 86 vol% methane + 14% nitrogen.
[2] Hydrogen (5.0) is purer than 99%.
[3] Energy density: natural gas 38 MJ/kg – hydrogen 120 MJ/kg.
Calorific value: natural gas 31.7 $MJ/m^3_n$ – hydrogen 10.8 $MJ/m^3_n$.

## Approach

A gas pressure regulating station, consisting of a spring loaded regulator, a safety shut-off valve (VA) and another safety shut-off valve (VAK(AAN)) mounted on the regulator and corresponding shut-off valves, filter and pipework, was made available on behalf of the grid operators for the purpose of carrying out the tests. Three different types of regulators were tested in this gas pressure regulating station. The capacity of the gas pressure regulating station (according to the gAvilar drawing, see Annex IV) is 100 $m^3_n/h$ (**natural gas**) at the minimum inlet pressure of 3 bar [4]. The nominal inlet pressure is 8 bar and the nominal outlet pressure is 100 mbar. The gas pressure regulating station is in compliance with NEN 1059:2019. Due to the size of the hydrogen flow rates vented in these tests, the tests were performed at the Twente Safety Campus in Enschede for permit-related reasons.

The gas pressure regulating station was first tested with **natural gas** up to a maximum of 200 $m^3_n/h$, which corresponds to the capacity of the regulator. The gas pressure regulating station was then tested using **hydrogen** up to a maximum flow rate of 600 $m^3_n/h$. The maximum gas velocity in the outgoing pipe of the gas pressure regulating station for natural gas is 20 m/s (through a DN50 pipe at 100 mbar) as specified in NEN 1059:2019. This was chosen so that all of the intended gas pressure regulation valves could be tested in one type of gas pressure regulating station. This made it possible to test whether the outgoing gas velocity caused any disturbance to the sensing line from the spring loaded regulators.

A HAS (high pressure delivery station) was also made available, consisting of a (spring loaded) regulator and two safety shut-off valves (VAK(AAN))) and associated valves, filter and pipework. The capacity of the pressure regulation station is approximately 30 $m^3_n/h$ (**natural gas**) at an inlet pressure of 4 bar [4]. The nominal inlet pressure is 8 bar and the nominal outlet pressure is 100 mbar. The gas pressure regulating station is in compliance with NEN 1059:2019.

The high pressure delivery station was first tested with natural gas up to a maximum flow rate of 30 $m^3_n/h$. The gas pressure regulating station was then tested with hydrogen up to a maximum flow rate of 90 $m^3_n/h$.

In order to carry out the tests, a measurement protocol was prepared and discussed with representatives of Netbeheer Nederland. The measurement protocol specified the steps, conditions and measurements to be taken for all the tests. With regard to the prescribed temperatures, it was established in advance that these could hardly be influenced, if at all, since the gases are delivered from cylinder packs and the measurements are conducted in the open air (not under laboratory conditions). The ambient temperature and the gas temperature during the measurements deviate from the temperatures as prescribed in the measurement protocol. This has no significant effect on the conclusions.

In the tests with hydrogen, the gas velocities are three times higher than with natural gas. It is important to establish that the pressure measured at the header of the exhaust line is representative of the ‘network pressure’, even if there is an increase in the gas flow rate. For this purpose, a buffer tank was installed on the outlet side, which significantly reduces the flow rate of the gas. This simulates the availability of a gas distribution network.

For some of the measurements, the standard test kit for gas pressure regulation installations, the PLEXOR, was used (see the measurement protocol, Chapter 3).

[4] In this report, overpressures have been mentioned (e.g. 3 bar corresponds to 4 bar absolute).

# 2. Gas pressure regulating station

## Gas pressure regulating station

Figure 1 shows the gas pressure regulating stations where the research was conducted. The district station is on the left and the high pressure delivery station is on the right [5].

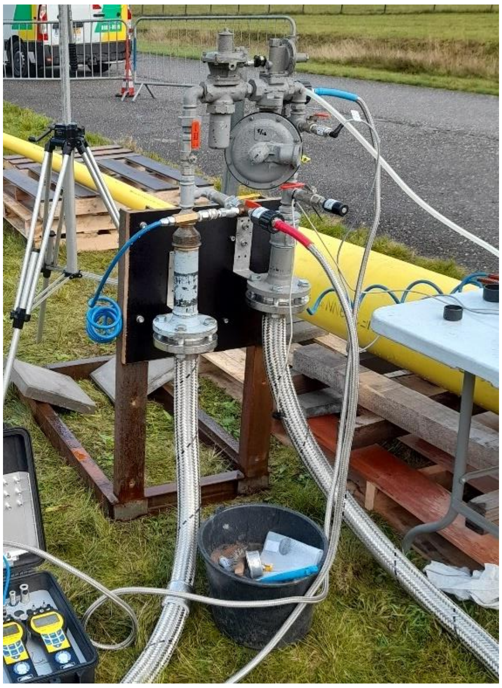

*Figure 1: At the left, the gas pressure regulating station (district station) and at the right, the high pressure delivery station (HAS)*

For the district station, the nominal inlet pressure is 8 bar, the nominal outlet pressure is 100 mbar and maximum capacity at 3 bar is 100 $m^3_n$/h **natural gas** ($L_{gas}$). Built in 2019, this station is equipped with a spring loaded regulator with a mounted VAK (VAK(AAN)). The inlet valve acts as a safety device controlled by combining an OPSO pneumax command valve and an Actuatech GD106 cylinder. Measurements were performed with the following three regulators:

1. An Itron 233.
2. An Elster-Instromet, type 243-12-1-SRL.
3. A Fiorentini, type DIVAL 600

During the measurements, the operation of the gas pressure regulating station was tested using both **natural gas** and **hydrogen** at an inlet pressure of 3 bar.

For the high pressure delivery station, the nominal inlet pressure is 4 or 8 bar and the nominal outlet pressure is 100 mbar. The capacity is about 30 $m^3_n$/h **natural gas** ($L_{gas}$) at 4 bar inlet pressure. The high pressure delivery station (HAS) is equipped with an IGA1843 and was also tested using **natural gas** and **hydrogen** at an inlet pressure of 3 bar.

5) A HAS is normally located in a mini cabinet but for this test it was mounted on a frame in the open air.

Figure 2 below shows all the regulators.

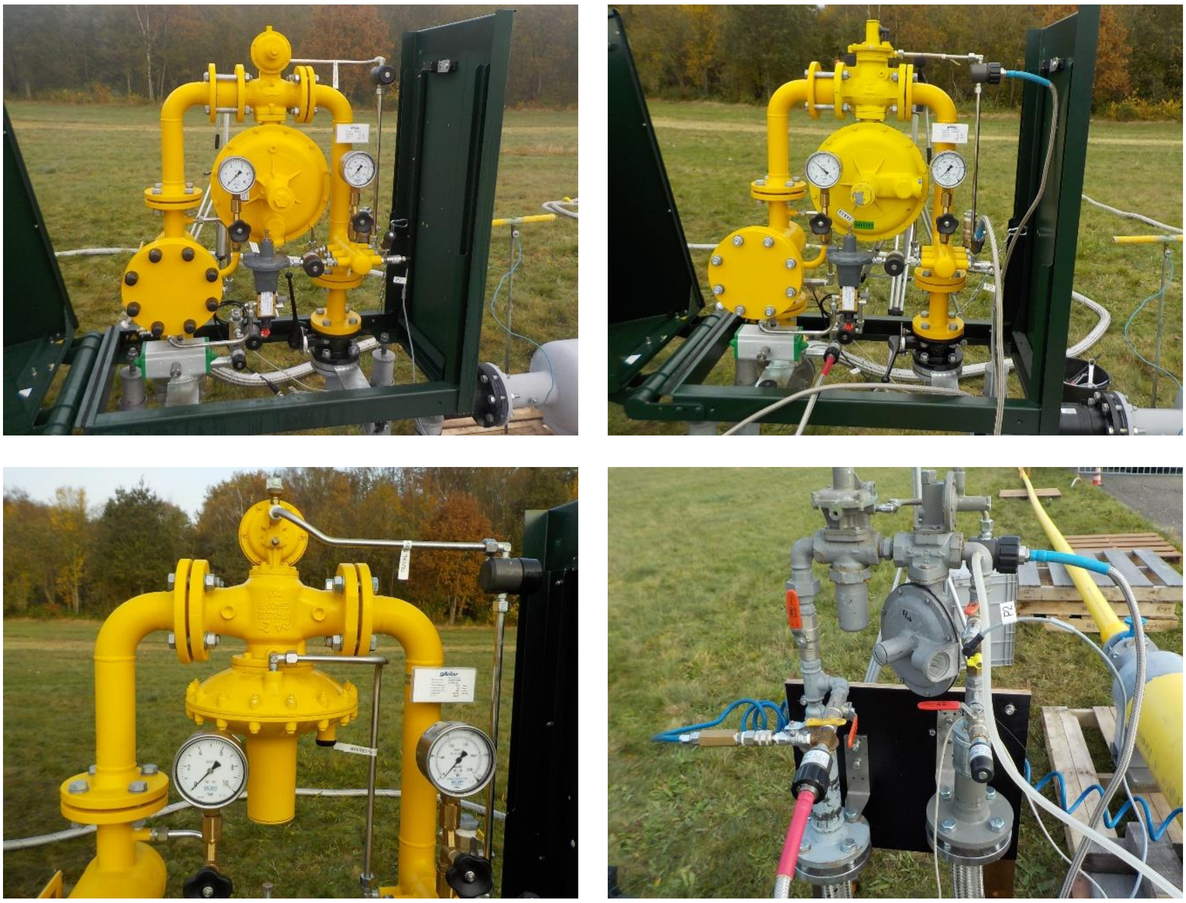

*Figure 2: All regulators tested in this programme; at the top left: the Itron 233, top right: the Elster Instromet 243, bottom left: the Fiorentini Dival 600 and bottom right: the IGA 1843.*

## Construction of the gas pressure regulating station

This is a single-line district station housed in a stainless steel casing (half cube cabinet) consisting of the following components:

- Inlet valve type ball valve that also serves as a safety valve (VA).
- Dust filter.
- Spring loaded pressure regulator with mounted safety device (safety shut-off valve (VAK(AAN))).
- Exhaust valve, butterfly valve type.

See Annex IV for a detailed description of the components used.

The structure of the HAS is very similar. The HAS is made up of the following components:

- Inlet valve, ball valve type (manual).
- Dust filter.
- VAK.
- Spring loaded regulator with mounted VAK(AAN).
- Exhaust valve, ball valve type.

See Annex IV for a detailed description of the components used.

## Gas pressure regulating station in the test setup

See Annex V for a diagram and photos of the test setup. This annex also includes an overview of the measuring points for the various pressure sensors.

# 3. Measurement protocol

This chapter contains the measurement protocol with a few preliminary remarks.

Comments:

- In this measurement protocol, natural gas is indicated with $CH_4$.
- The tests are performed with natural gas and hydrogen (indicated with $H_2$) with a minimum inlet pressure of 3 bar.
- The volumetric flow of $H_2$ is 3x the volumetric flow of natural gas.
- Natural gas refers to low-calorific natural gas (86 vol% methane + 14% nitrogen).
- The pressure settings with natural gas and hydrogen are identical.
- Where relevant, the tests are based on or derived from EN 334 and EN 14382.
- The tests may be combined.
- The ambient temperatures listed below may not be achievable due to the tests being performed outdoors.
- The same applies to the gas temperature, as the gas (natural gas or hydrogen) is supplied from cylinder packs where the pressure is reduced from a maximum of 200 bar to 3 bar.
- Prior to the tests, the external leak tightness of the gas stations must be demonstrated (for both natural gas and hydrogen) using a leak detector ($CH_4$ / $H_2$) and a bubble solution.

The following measurements and checks (1 to 8) are performed in succession;

1. Do the inlet and outlet valves close properly (internally)?
2. Does the VA respond when the correct pressure is set?
   2.1. And within the allotted time?
3. Does the VA close completely (internally)?
4. Does the VAK respond when the correct pressure is set?
5. Does the VAK close completely (internally)?
6. What is the closing pressure/tightness of the regulator?
7. What is the control behaviour when using natural gas and hydrogen?
   - Does the regulator control properly (stably) using $H_2$ as it does using natural gas with different flow rates and rapid flow rate changes as well as low flow rates and potential oscillation?
   - Does the regulator oscillate?
8. Capacity test for regulator if the volume flow is increased 3 times at Pi = 3 bar (i.e. 3x KG value).
   - Effect on sensing and measuring lines (for options 1 and 4)
   - Effect on regulation (regulator) (for options 1 and 4)
   - Effect on safety devices (correct response)
   - Does the filter work with H2? (pressure difference in relation to velocities)
   - What are the noise effects?

A. Measurement number 1: Internal tightness, inlet valve and outlet valve

This test was carried out **once** with $CH_4$ and with $H_2$

a. Inlet valve (VA)

b. Outlet valve

Inlet pressure 3 bar (+/- 0.1 bar)
Initial outlet pressure 90 mbar
Ambient temperature 15 °C +/- 5 °C
Gas temperature 15 °C +/- 5 °C
Accuracy of pressure measurement +/- 1 mbar
Pressure monitoring for 15 minutes with 3 bar inlet pressure and blocked regulator

Criteria: the acceptance criteria according to NEN-EN12266-1-2012, rate C (see Annex VI)

B. Measurement numbers 2 and 4: Response pressure of safety devices (without flow)
This test is carried out **three times** for each measurement (2 and 4) with $CH_4$ and with $H_2$
Ambient temperature 15 °C +/- 5 °C
Carried out with test kit (PLEXOR)
Accuracy of pressure measurement +/- 0.1 mbar

Criteria: according to NEN 1059, Article 9.31: The pressure protection system should activate automatically if, in the event of a failure of the pressure control system, the pressure in the downstream system exceeds the permissible limits. Account must be taken of the likely deviations of the pressure protection system from the set values (accuracy class (NK))

C. Measurement numbers 3 and 5: Leak tightness (internal) of activated safety devices
This test is carried out **once** with $CH_4$ and with $H_2$
Inlet pressure 3 bar (+/- 0.1 bar)
Initial outlet pressure 100 mbar
Ambient temperature 15 °C +/- 5 °C
Gas temperature 15 °C +/- 5 °C
Carried out with test kit (PLEXOR)
Pressure monitoring for 15 minutes with 3 bar inlet pressure and closed regulator, and for 15 minutes at 100 mbar with open regulator

Criteria: the acceptance criteria according to NEN-EN12266-1-2012, rate C (see Annex VI)

D. Measurement number 6: Closing pressure / internal gas tightness of the regulator
This test was carried out **twice** with $CH_4$ and with $H_2$ (i.e., 4 measurements)
Programmed closing of the outlet valve in 1 to 2 seconds at initial flow of 30 $m^3{}_n$/h $CH_4$ and 90 $m^3{}_n$/h $H_2$ (Itron, Elster and Fiorentini) and 5 $m^3{}_n$/h $CH_4$ and 15 $m^3{}_n$/h $H_2$ (IGA)
Inlet pressure 3 bar (+/- 0.1 bar)
Initial outlet pressure 100 mbar
Volume at outlet > 0.2 $m^3$ between the regulator and the control valve

Criteria: no significant difference in closing pressure in the application with CH4 and H2

E. Measurement number 7: Control behaviour
This test was performed twice with $CH_4$ and with $H_2$ (i.e., 4 measurements)
Inlet pressure 3 bar (+/- 0.1 bar)
Initial outlet pressure 100 mbar
Ambient temperature 15 °C +/- 5 °C
Gas temperature 15 °C +/- 5 °C
Pressure measurement +/- 1 mbar
Flow rate increase/decrease controlled from min to max
Speed of flow rate change from minimum to maximum and back to minimum in 10 minutes.
Pressure and flow rate electronically recorded with a time resolution of better than 5 $s^{-1}$
Average flow rate (one time) per 10 s, accuracy better than +/- 15%
Control valve operated programmatically

Criteria: no significant difference in outlet pressure and pressure stability in the application with $CH_4$ and $H_2$

F. Measurement number 8: Capacity – outlet pressure and pressure stability during supply and discharge
This test was carried out twice with $CH_4$ and with $H_2$ (i.e., 4 measurements). Different partial measurements are applicable for the 4 options (see table 1)
Inlet pressure 3 bar (+/- 0.1 bar)
Initial outlet pressure 100 mbar
Ambient temperature 15 °C +/- 5 °C
Gas temperature 15 °C +/- 5 °C
Controlled flow rate increase and decrease (use max value of $CH_4$ when applying $H_2$and then increase 3 times)
Speed of flow rate change from minimum to maximum and back to minimum in 10 minutes

Pressure and flow rate electronically recorded with a time resolution of better than 5 $s^{-1}$
Average flow rate (one time) per 10 s, accuracy better than +/- 15%
Control valve operated programmatically

Additionally for each sub-measurement:

F1 Register pressures on sensing and measuring lines (measurements on the header and on the buffer tank).
F2 Register outgoing pressure.
F3 Determine the effect on safety devices using the results of the sensing and measuring lines as the basis (do not actually allow VA and VAK to drop), possibly an additional measuring point (if the sensing line is not on the header).
F4 Monitor filter pressure difference during flow rate change, also take a picture before and after the measurements of the filter used (for natural gas and for hydrogen).
F5 Record noise using a noise meter. At a distance of one metre and at a height of one metre above the bottom of the cabinet.

Criteria: no significant difference in behaviour with the application of $CH_4$ and with $H_2$

*Table 1* – Overview of measurements to be carried out per regulator

| | | Itron 233 | E-Instromet 243-12-1-SRL | Fiorentini Dival 600 | IGA 1843 |
|---|---|---|---|---|---|
| **Measurement no.** | **Description of measurement** | | | | |
| **1** | Internal tightness of inlet and outlet valve | V | - | - | V |
| **2** | Procedure VA | V | - | - | V** |
| **2.1** | Closing time VA | V | - | - | V** |
| **3** | Internal tightness VA | See 1 | V | V | V** |
| **4** | Procedure VAK | V | V | V | V |
| **5** | Internal tightness VAK(AAN) | V | V | V | V |
| **6** | Closing pressure/internal tightness of regulator | V | V | V | V |
| **7** | Control behaviour | V | V | V | V |
| **8** | Capacity | V | V | V | V |
| **8.1** | Effect of sensing and measurement lines | V | V | V | V |
| **8.2** | Effect on regulation | See 8.1 | See 8.1 | See 8.1 | See 8.1 |
| **8.3** | Effect on safety devices | See 8.1 | See 8.1 | See 8.1 | See 8.1 |
| **8.4** | Complies with filter $H_2$ | V | V | V | V |
| **8.5** | Noise measurement | V | V | V | V |

**V = test**
**- = do not test**
***Measuring capacity with Fiorentini Dival limited to 600 $m3_n/h$ $H_2$ due to the gas velocity in the outlet line and the limiting capacity of the gas regulation station itself.**
****HAS has two VAKs, one of which has the function of VA.**

Comments (deviations in implementation as compared to original plan):

- The control valve behind the buffer tank could not be operated in a programmed manner (the control of the valve suffered a defect) prior to the start of the testing period. The tests with the high pressure delivery station were repeated at a later stage with a different, motor-operated valve.
- Pressure transducer P1 suffered a defect after measurement day 1. P1 is related to the incoming pressure; this was monitored with the analogue pressure gauge.
- The available data logger recorded much less frequently than anticipated due to a delivery problem with the logger that was originally ordered. This original data logger only arrived in Apeldoorn at the end of measurement day 2 and was not calibrated.
- Logging the flow rate as it was done with the HAS cabinet (mass flow meter / rotor meter) turned out to be impossible in the first series of measurements. For this reason a manual recording was performed for measurements 1 to 6. Tests 7 and 8 were carried out again at a later stage using a different rotor meter that was capable of logging.
- External leaks on the installations were tested using a bubble solution.

The district station was initially connected with a flexible pipe at the inlet and a flexible pipe at the outlet (both measuring 8 metres in length and with an internal diameter of 54 mm, with a ribbed interior). The flexible pipe at the outlet (between the station and the buffer tank) caused so much resistance that the pressure in the buffer tank failed during the measurements with the Itron 233 regulator. At a flow rate of 150 $m^3_n$/h for natural gas, the pressure directly after the regulator was 100 mbar and in the buffer tank 5 mbar. At a flow rate of 600 $m^3_n$/h for hydrogen, the pressure directly after the regulator was 100 mbar and in the buffer tank 25 mbar. For this reason, the flexible pipe was removed during the measurements with the gas station, and the buffer tank was directly connected to the outlet of the gas station. This modification allowed the tests to be conducted correctly.

# 4. Measurement results – Itron 233 regulator

This chapter contains the measurement results from the measurements on the district station containing the Itron 233 regulator. The measurement results are shown according to the measurement sequence and the test numbering as stated in the measurement protocol. During the measurements, the temperature averaged 12.2 degrees (with a standard deviation of 0.4 degrees). All measurement results are included in Annex XII of this report.

## 4.1 Leak tightness (internal) - measurement number 1

The capacity of the section between the inlet valve (VA) and the manually operated shut-off valve is approximately 35 $dm^3$. For the leak tightness calculations, other capacity values are also required. Thus the capacity between the VA and the VAK was set at 6.7 $dm^3$, the capacity between the VAK and the outlet valve at 8.8 $dm^3$, the capacity between the VA and the shut-off valve at 15.5 $dm^3$ and the capacity between the outlet valve, plastic "short radius bend" and the butterfly valve behind the pressure vessel at 203.9 $dm^3$. (218.3 $dm^3$ with flexible hose).

### 4.1.1 Inlet shut-off valve (safety shut-off valve VA)

The safety valve (VA) is closed, the VAK is open and the manual shut-off valve between the VAK and the buffer tank is closed. The butterfly valve behind the buffer tank is also closed and the pressure in front of the safety valve is 3 bar.

**Natural gas**
The average leakage rate over the entire 15-minute period was 0.16 mbar/min. This equates to a leakage of 37.8 ± 10% $mm^3/s$.

**Hydrogen**
The average leakage rate over the entire 15-minute period was 0.14 mbar/min. This equates to a leakage of 33.1 ± 10% $mm^3/s$.

Comments:

- For the acceptance criteria according to NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- The inlet valve complies with Rate C (3.0 * DN = 150 $mm^3/s$).

**Conclusion**: the internal leak tightness of the inlet valve complies with the requirements.

### 4.1.2 Outlet valve (manually operated)

To determine the leak tightness of the manually operated outlet valve, the VA is closed, the VAK is open, the manually operated valve is closed and the butterfly valve behind the pressure vessel is closed. 3 bar for the VA, approximately 90 mbar between the VA and the manually operated valve and atmospheric between the manually operated valve and the butterfly valve. The procedures for the various tests are described in Annex XII under the table.

**Natural gas**
The average leakage rate over the entire 15-minute period was 0.013 mbar/min. This equates to a leakage of 48.0 ± 10% $mm^3/s$.

**Hydrogen**
The average leakage rate over the entire 15-minute period was 0.17 mbar/min. This equates to a leakage of 623.1 ± 10% $mm^3/s$.

Comments:

- For the acceptance criteria in accordance with NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- During the measurement with hydrogen, the buffer tank was in the shade, causing a pressure drop due to the influence of temperature (Gay-Lussac's law ($P1/T1 = P2/T2$) clearly shows the temperature effect). The same measurement with natural gas shows a slight pressure increase. This suggests a large leakage measured for hydrogen, which is not the case when looking at the results with natural gas. Based on this, it is concluded that the outlet valve complies with Rate C (3.0 * DN = 150 $mm^3/s$).

**Conclusion**: the internal leak tightness of the outlet valve meets the requirements.

## 4.2 Protective device response pressures – measurement number 2 and 4

The response pressures – as well as the closing time for the VA – are listed in the following tables.

*Table 2 – Response pressure and closing time VA*

| Safety valve VA - Set value is 180 mbar*) | | | |
|---|---|---|---|
| **Medium** | **Response pressure [mbar]** | **Closing time [s]** | **Inlet pressure (nominal) [bar]** |
| Natural gas | 180 | < 1 | 3 |
| | 180 | < 1 | 3 |
| | 180 | < 1 | 3 |
| | | | |
| Hydrogen | 182 | < 1 | 3 |
| | 181 | < 1 | 3 |
| | 180 | < 1 | 3 |

*) The safety devices are set according to the pressure read on the analogue pressure gauge for the gas line concerned. This involves a certain inaccuracy as compared to the digital pressure gauge during the tests. Given the (average) measuring results for natural gas, a set value for the VA of 180 mbar was assumed.

*Table 3 – Response pressure VAK(AAN)*

| Safety shut-off valve VAK(AAN) - Set value is 180 mbar*) | |
|---|---|
| **Medium** | **Response pressure [mbar]** |
| Natural gas | 179 |
| | 179 |
| | 181 |
| | |
| Hydrogen | 179 |
| | 179 |
| | 177 |

*) The safety devices are set according to the pressure readings on the pressure gauge of the gas line concerned. This involves a degree of inaccuracy with respect to the calibrated pressure gauge during the tests. Given the (average) measuring results for natural gas, a set value for the VAK(AAN) of 180 mbar is assumed.

Table 2 – shows that the response pressure for the VA in **natural gas** is very constant at 180 mbar. This complies with the criteria of NK 1 (permissible deviation ±1.8 mbar). With **hydrogen**, the response pressure also hardly varies; the measured values are between 180 and 182 mbar. The variation with **hydrogen** is of a similar size and also complies with NK 1. It was assumed that the response pressure of the VAK(AAN) was set at 180 mbar.

Table 3 shows that the response pressure for the VAK(AAN) with **natural gas** varies between 179 and 181 mbar. This complies with the criteria of NK 1 (permissible deviation ±1.8 mbar). With **hydrogen**, the response pressure varies between 177 and 179 mbar. Strictly speaking, the last measurement of 177 mbar does not fall within the NK 1, but twice the response pressure at 179 mbar is a good reading. Based on this reasoning, the VAK(AAN) also complies with NK 1. It was assumed that the response pressure of the VAK(AAN) was set at 180 mbar.

**Conclusions**:

- The closing time of the VA complies with the standard.
- The variation in response pressure at both the command valve (of the VA) and the VAK(AAN) with **hydrogen** is approximately the same as with **natural gas**.
  The command valve for **hydrogen** does comply with the NK (set for natural gas).

## 4.3 Leak tightness (internal) of activated safety devices – measurement number 3 and 5

### 4.3.1 Safety valve

For the VA section, see 4.1.1.

### 4.3.2 Safety shut-off valve

**Natural gas**

The average leakage rate over the entire 15-minute period was 0.21 mbar/min. This equates to a leakage of 27.7 ± 10% $mm^3/s$.

**Hydrogen**

The average leakage rate over the entire 15-minute period was 0.03 mbar/min. This equates to a leakage of 5.8 ± 10% $mm^3/s$.

Comments:

- For the acceptance criteria according to NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- During the measurement with hydrogen, the test setup was placed in the shade, which led to a pressure drop being measured due to the influence of temperature (Gay-Lussac's law (P1/T1 = P2/T2) clearly shows the temperature effect). Based on this, it is concluded that the outlet valve complies with Rate C (3.0 * DN = 150 $mm^3/s$).

**Conclusion**: the internal leak tightness of the safety shut-off valve meets the requirements.

## 4.4 Closing pressure when closing the control valve – measurement number 6

The closing pressures for the measurements on the Itron 233 regulator are shown in table 3.

*Table 4 – Closing pressures*

| Medium | Inlet pressure [bar] | Closing pressure [mbar] |
|---|---|---|
| Natural gas | 3 | 108.0 |
| | 3 | 108.0 |
| | | |
| Hydrogen | 3 | 108.8 |
| | 3 | 108.2 |

**Conclusion**: the closing pressure with **natural gas** is almost identical to the closing pressure of **hydrogen**.

## 4.5 Control behaviour – measurement number 7 and 8

Figure 3 shows the result of the measurement with **natural gas** and Figure 4 show the result with **hydrogen**, where the flow rate was gradually increased for thirty seconds and then decreased again by thirty seconds. The measurement was performed twice in the same manner. The pressure in the grid (represented by the buffer tank) was lowered to 70 mbar to see how the regulator would open up further (and deliver more gas) to accommodate this. In the case of the Itron 233 a maximum flow rate of 180 $m^3_n/h$ was reached for **natural gas** instead of the expected 205 $m^3_n/h$. The regulator opens less than requested as a correction for this pressure drop and is therefore already at the upper end of the range. See Annex VII for the graphs from the second measurement.

Based on a duplicate measurement for natural gas, the pattern appears consistent. The maximum flow rate of around 180 $m^3_n/h$ falls short of the expected 205 $m^3_n/h$. Because the demand from the grid is higher (simulated by the pressure drop to 70 mbar), the pressure drops further (to around 40 mbar).

Based on the allocated regulation class (RK 5) for the Itron 233 regulator, the deviation is more than the permissible amount for this measurement.

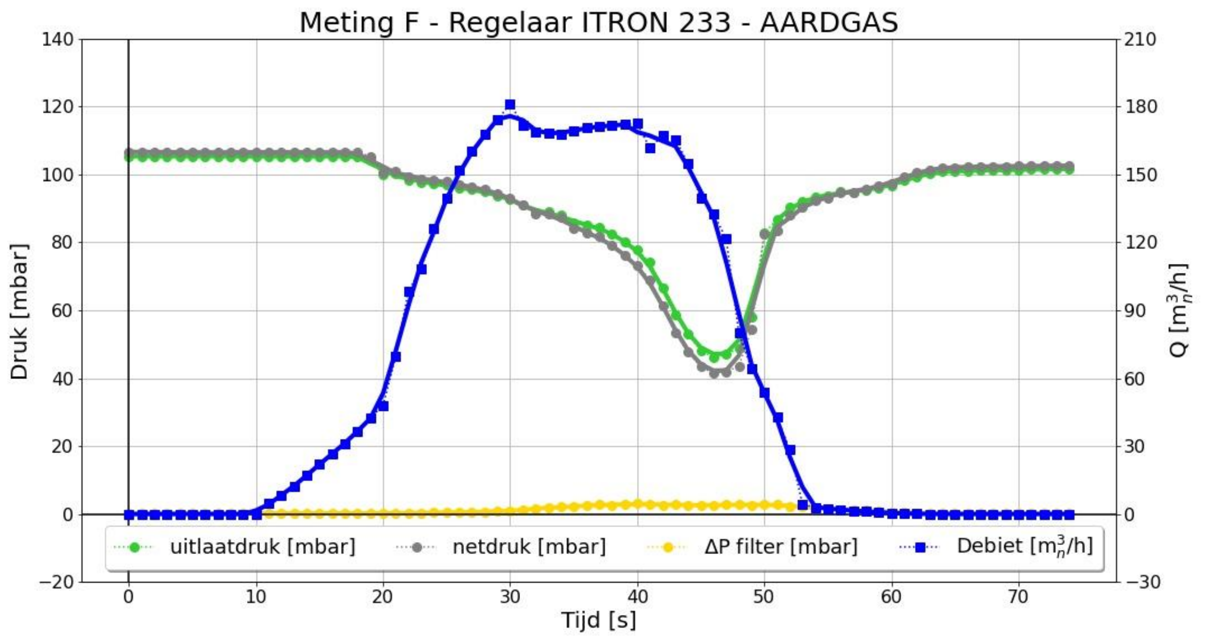


*Figure 3: Pressure stability with an increasing and decreasing flow rate – natural gas*

Explanation of the graph:

- The **blue** line is the flow rate converted to $m^3_n/h$, indicated on the secondary y-axis.
- The thick **orange** line is the measured pressure difference over the filter with 1 measurement per second. This pressure is measured in the 3 bar section, the maximum pressure drop over the filter is about 3 mbar.
- The thick **green** line is the outlet pressure measured at the header of the station. This line is the average over 70 measurements (= 70 seconds).
- The **grey** line is the ‘net pressure’, the pressure measured per 1 second at the buffer tank DN 400.

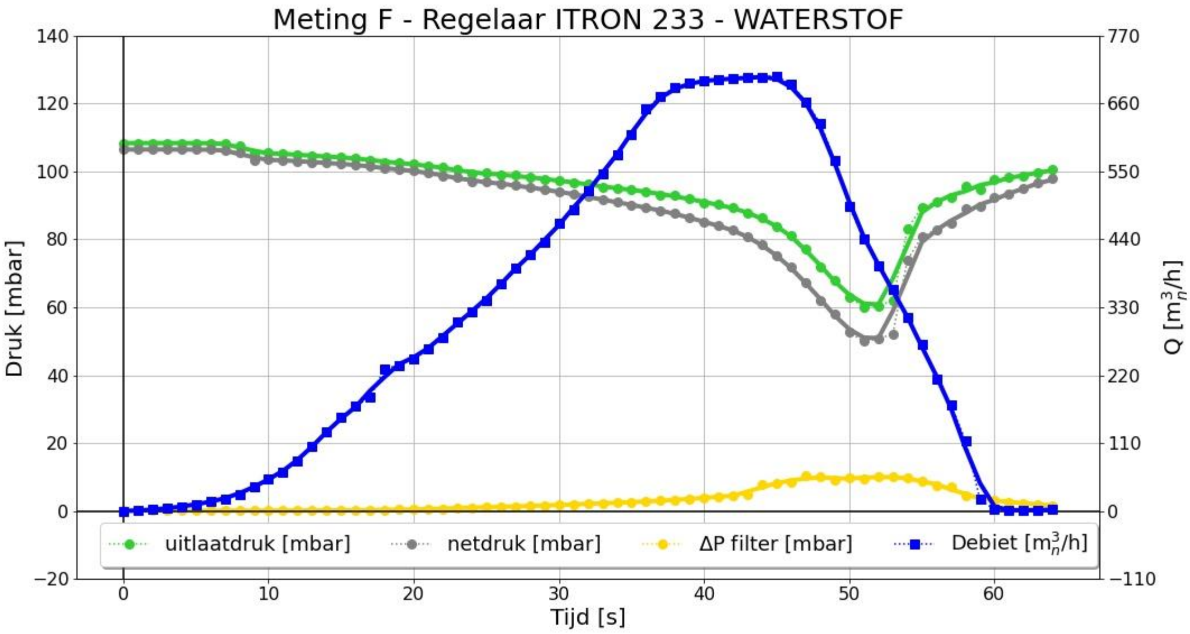


*Figure 4: Pressure stability with an increasing and decreasing flow rate – hydrogen*

In the case of Itron 233, a maximum flow rate of **hydrogen** of over 600 $m^3{}_n$/h was reached. This corresponds well with expectations. The regulator controls the opening as a correction for this pressure drop but is at the upper end of the range (the blue curve flattens out).

Based on a duplicate measurement for hydrogen, the pattern appears consistent. The maximum flow rate of over 600 $m^3{}_n$/h is in line with expectations. Because the demand from the grid is higher (simulated by the pressure drop to 70 mbar), the pressure drops to around 50 mbar.

Based on the allocated regulation class (RK 5) for the Itron 233 regulator, the deviation is more than the permissible amount for this measurement.

<u>Explanation of the graph:</u>

- The thick orange line is the measured pressure drop across the filter at 1 measurement per second. This pressure is measured in the 3 bar section, the maximum pressure drop across the filter is about 12 mbar, which is measured <u>after</u> the maximum flow rate is reached. This effect may be caused by turbulence but is not compatible with the observations of other pressure drop measurements across the filter. However, this observation has been determined in duplicate for hydrogen, indicating consistency in the way of measurement.
- For the explanation of the above figure, see Figure 3.

## 4.6 Noise emission

The noise emissions were measured both for **natural gas** and for **hydrogen**. The noise measurement was carried out with a Bruel & Kjaer 2250 analyser mounted on a tripod. The microphone of the sound meter was placed at a distance of one metre and at a height of one metre above the bottom of the cabinet.

In addition to the spectrum, this sound meter measures the “surface weighted average” of the sound level spectrum, the so-called LAeq. As a result, short-lived, high measurements are not included in this average. According to the protocol, the capacity measurements were carried out at 200 $m^3_n/h$ (=100%) **natural gas** and 600 $m^3_n/h$ (=100%) **hydrogen**.

During the measurement of the control behaviour with the Itron 233 regulator, as described in section 4.5, an LAeq of 61.6 dB was measured for **natural gas**.

During the measurement of the control behaviour Itron 233 regulator, as described in section 4.5, an LAeq of 58.4 dB was measured for **hydrogen**.

Comments:
The flow rate during the noise measurement deviates slightly from the intended flow rates according to the measurement protocol. For **natural gas**, the noise measurement was carried out at 180 $m^3_n/h$ (which corresponds to 90% of the intended value in the protocol). For **hydrogen**, the noise measurement was carried out at 700 $m^3_n/h$ (which corresponds to 115% of the intended value in the protocol). Because of this, the values cannot be compared completely one-to-one.

It should be taken into account that components near the test setup also influenced the noise measurement. These effects were not filtered out.

**Conclusion**: the noise emission with the application of **hydrogen** (at a flow rate of 700 $m^3_n/h$) is 3.2 dB(A) lower than with **natural gas** natural gas (at a flow rate of 180 $m^3_n/h$). If hydrogen had been exactly three times as much, then the noise emission would have been even lower.

# 5. Measurement results – Elster Instromet 243 regulator

This chapter contains the measurement results for the district station containing the Elster-inflow243 regulator. The measurement results are shown according to the measurement sequence and the test numbering as stated in the measurement protocol. During the measurements, the temperature was 12.2 degrees on average (with a standard deviation of 0.2 degrees). All measurement results are included in Annex XII of this report.

The measurements of the inlet and outlet valve (safety valve (VA) and manual valve) were not repeated as they are not different from the tests with the Itron 233 regulator.

## 5.1 Response pressure of safety devices – measurement number 2 and 4

The response pressures of the VAK(AAN) are listed in the table below.

*Table 5 – Response pressure VAK(AAN)*

| Safety shut-off valve VAK(AAN) - Set value is 195 mbar*) | |
|---|---|
| **Medium** | **Response pressure [mbar]** |
| Natural gas | 195 |
| | 194 |
| | 196 |
| | |
| Hydrogen | 195 |
| | 194 |
| | 193 |

*) The safety devices are set according to the pressure read on the analogue pressure gauge for the gas line concerned. This involves a certain inaccuracy as compared to the digital pressure gauge during the tests. Given the (average) measuring results for natural gas, a set value for the VAK(AAN) of 195 mbar is assumed.

Table 5 - shows that the response pressure for the VAK(AAN) with **natural gas** varies between 194 and 196 mbar. This complies with the criteria of NK 1 (permissible deviation ± 1.9 mbar). With **hydrogen**, the response pressure varies between 193 and 195 mbar. The variation with **hydrogen** is of a similar size and also complies with NK 1. It was assumed that the response pressure of the VAK(AAN) was set at 195 mbar.

**Conclusions**:

- The variation in response pressure for the VAK(AAN) is approximately the same for **hydrogen** as it is for **natural gas**.

## 5.2 Leak tightness (internal) of activated safety devices – measurement number 3 and 5

### 5.2.1 Safety valve

For the VA section, see 4.1.1.

### 5.2.2 Safety shut-off valve

**Natural gas**

The average leakage value throughout the entire 15-minute period was 0.16 mbar/min. This equates to a leakage of 23.1 ± 10% mm³/s.

**Hydrogen**

The average leakage value throughout the entire 15-minute period was 0.07 mbar/min. This equates to a leakage of 9.6 ± 10% mm³/s. This outcome cannot be explained logically but may have been caused by temperature fluctuations.

Comments:

- For the acceptance criteria according to NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- The inlet valve complies with Rate C (3.0 * DN = 150 mm³/s).

**Conclusion**: the internal leak tightness of the safety shut-off valve meets the requirements.

## 5.3 Closing pressure when closing the control valve – measurement number 6

The closing pressures for the measurements on the Elster Instromet 243 regulator are shown in Table 6.

*Table 6 – Closing pressures*

| Medium | Inlet pressure [bar] | Closing pressure [mbar] |
|---|---|---|
| Natural gas | 3 | 105.3 |
| | 3 | 105.4 |
| | | |
| Hydrogen | 3 | 102.5 |
| | 3 | 102.1 |

Comment:

- The differences in closing pressure may have been caused by speed variation when closing the manually operated control valve.

**Conclusion**: the closing pressure for **natural gas** is on average 3 mbar higher than the closing pressure for **hydrogen**.

## 5.4 Control behaviour – measurement number 7 and 8

Figure 5 shows the result of the measurement with **natural gas** and Figure 6 show the result with **hydrogen**, where the flow rate was gradually increased for thirty seconds and then decreased again by thirty seconds. The measurement was performed twice in the same manner. The pressure in the grid (represented by the buffer tank) was lowered to 70 mbar to see how the regulator would open up further (and deliver more gas) to accommodate this. In the case of the Elster Instromet 243, a maximum flow rate of 170 $m^3_n/h$ was reached instead of the expected 200 $m^3_n/h$. The regulator opens less than requested as a correction for this pressure drop and is therefore already at the upper end of the range. For the graphs from the second measurement, see Annex VIII.

Based on a duplicate natural gas measurement, the pattern is approximately the same. The maximum flow rate of around 170 $m^3_n/h$ falls short of the expected 200 $m^3_n/h$. As the demand from the grid is higher (simulated by the pressure drop to 70 mbar), the pressure drops a little further (to around 60 mbar).

Based on the allocated regulation class (RK 5) for the Elster-instromet 243 regulator, the deviation is more than the permissible amount for this measurement.

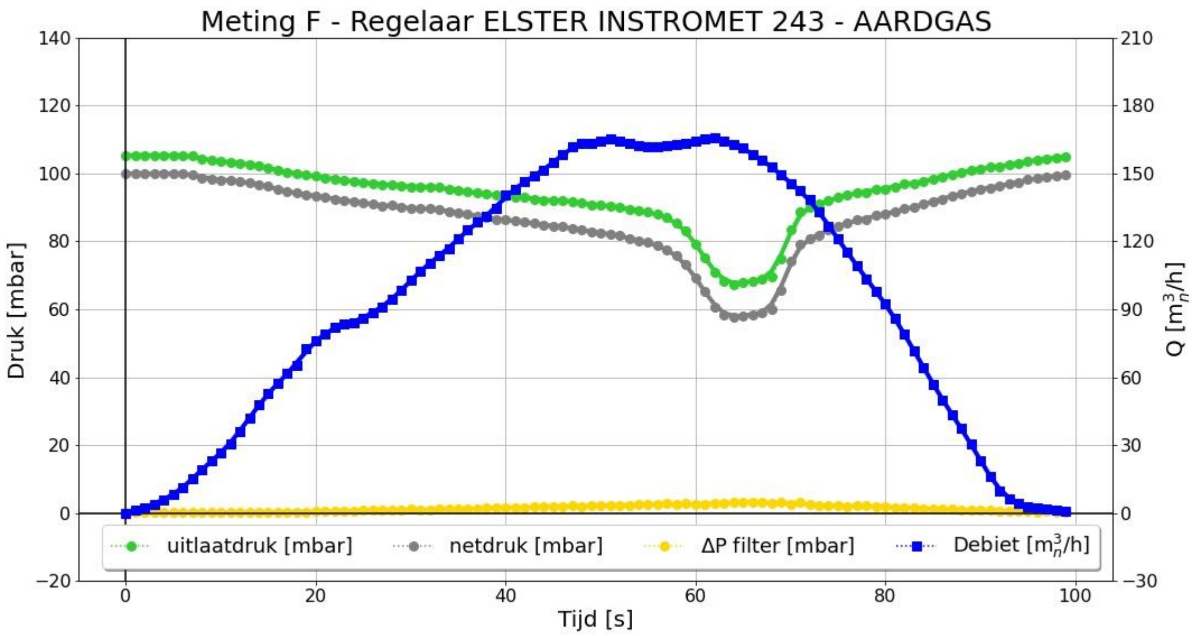


*Figure 5: Pressure stability with an increasing and decreasing flow rate – natural gas*

Explanation of the graph:

- The **blue** line is the flow rate converted to $m^3_n/h$, indicated on the secondary y-axis.
- The thick **orange** line is the measured pressure difference over the filter with 1 measurement per second. This pressure is measured in the 3 bar section, the maximum pressure drop over the filter is again about 3 mbar.
- The thick **green** line is the outlet pressure measured at the header of the station. This line is the average over 70 measurements (= 70 seconds).
- The **grey** line is the 'net pressure', the pressure measured per 1 second at the buffer tank DN 400.

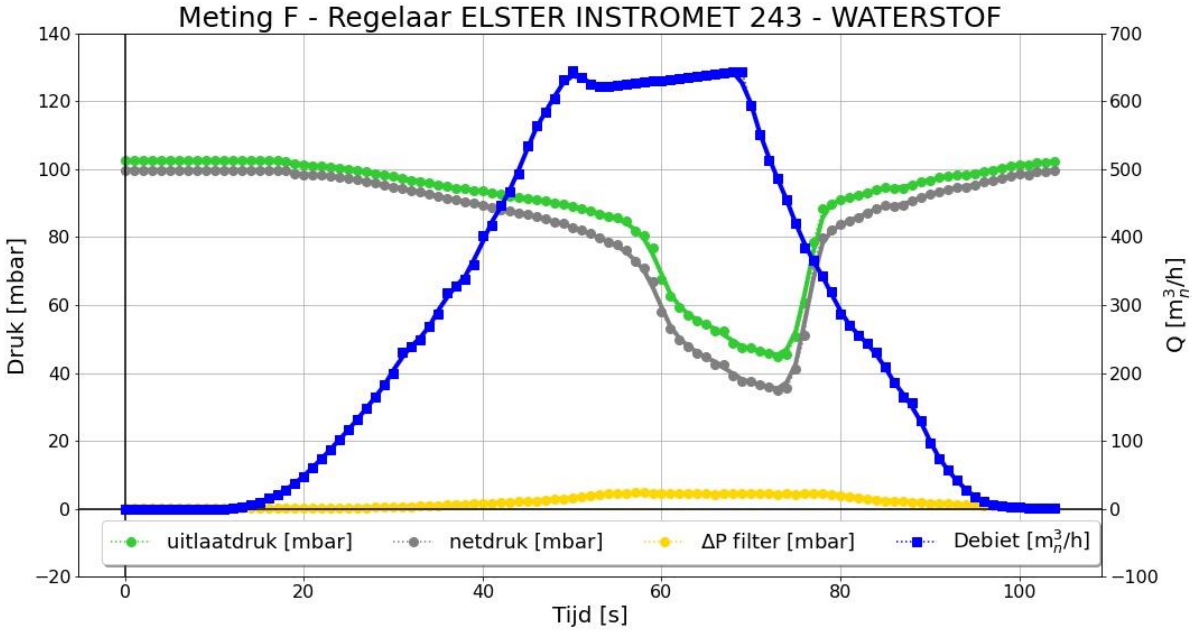


*Figure 6: Pressure stability with an increasing and decreasing flow rate – hydrogen*

In the case of the Elster Instromet 243, a maximum flow rate for **hydrogen** was reached of over 600 $m^3_n/h$. This corresponds well with expectations. The regulator controls the opening as a correction for this pressure drop but is at the upper end of the range (the blue curve flattens out). In the second measurement, the flow rate remained just below the maximum so that no flattening of the curve could be seen (see Annex VIII).

Based on a duplicate measurement for hydrogen, the pattern is approximately the same. The maximum flow rate of over 600 $m^3_n/h$ is in line with expectations. Because the demand from the grid is higher (simulated by the pressure drop to 70 mbar), the pressure drops to about 40 mbar at the first measurement. In the second measurement the pressure drops less and remains at about 60 mbar. The explanation for the difference may lie in reaching the maximum capacity as described above.

Based on the allocated regulation class (RK 5) for the Elster-instromet 243 regulator, the deviation is more than the permissible amount for this measurement.

Explanation of the graph:

- The thick **orange** line is the measured pressure difference over the filter with 1 measurement per second. This pressure was measured in the 3 bar section, the maximum pressure drop across the filter is approximately 5 mbar.
- The **blue** line is the flow rate converted to $m^3_n/h$, the flow rate is indicated on the secondary y-axis. The abrupt flattening of the trend indicates that the maximum measuring range has been reached.
- For the explanation of the above figure, see Figure 5.

## 5.5 Noise emission

The noise emissions were measured both for **natural gas** and for **hydrogen**. The noise measurement was carried out with a Bruel & Kjaer 2250 analyser mounted on a tripod. The microphone of the sound meter was placed at a distance of one metre and at a height of one metre above the bottom of the cabinet.

In addition to the spectrum, this sound meter measures the “surface weighted average” of the sound level spectrum, the so-called LAeq. As a result, short-lived, high measurements are not included in this average. According to the protocol, capacity measurements were carried out at 200 $m^3_n$/h (=100%) **natural gas** and 600 $m^3_n$/h (=100%) **hydrogen**.

During the measurement of the control behaviour with the Elster Instromet regulator, as described in section 5.4, an LAeq of 55.4 dB was measured for **natural gas**.

During the measurement of the control behaviour with the Elster Instromet regulator, as described in section 5.4, an LAeq of 56.7 dB was measured for **hydrogen**.

The difference in noise levels for this regulator is minimal.

Comments:
The flow rate during the noise measurement deviates slightly from the intended flow rates according to the measurement protocol. For **natural gas**, the noise measurement was carried out at 170 $m^3_n$/h (which corresponds to 85% of the intended value in the protocol). For **hydrogen** the noise measurement was carried out at 660 $m^3_n$/h (corresponding to 110% of the target value in the protocol). Because of this, the values cannot be compared completely one-to-one.

It should be taken into account that components near the test setup also influenced the noise measurement. These effects were not filtered out.

**Conclusion**: the noise emission with the application of **hydrogen** (at a flow rate of 660 $m^3_n$/h) is 1.3 dB(A) higher than with **natural gas** (at a flow rate of 170 $m^3_n$/h). The difference is therefore very small, and a comment should be made about the range of capacity.

# 6. Measurement results – Fiorentini Dival 600 regulator

This chapter contains the results for the measurements of the district station with the Fiorentini Dival600 regulator. The measurement results are shown according to the measurement sequence and the test numbering as stated in the measurement protocol. During the measurements, the temperature averaged 8.3 degrees (with a standard deviation of 0.9 degrees). All measurement results are included in Annex XII of this report.

The measurements of the inlet and outlet valves were not repeated as they are not different from the tests with the Itron regulator.

## 6.1 Response pressure of safety devices – measurement number 2 and 4

The response pressures of the VAK(AAN) are listed in the table below.

*Table 7 – Response pressure VAK(AAN)*

| Safety shut-off valve VAK(AAN) - Set value is 180 mbar*) | |
|---|---|
| **Medium** | **Response pressure [mbar]** |
| Natural gas | 182 |
| | 181 |
| | 181 |
| | |
| Hydrogen | 180 |
| | 180 |
| | 179 |

*) The safety devices are set according to the pressure read on the analogue pressure gauge for the gas line concerned. This involves a certain inaccuracy as compared to the digital pressure gauge during the tests. Given the (average) measuring results for natural gas, a set value for the VAK(AAN) of 180 mbar is assumed.

Table 7 – shows that the response pressure for the VAK(AAN) with **natural gas** ranges between 181 and 182 mbar. This complies with the criteria of NK 1 (permissible deviation ±1.8 mbar). With **hydrogen**, the response pressure varies between 179 and 180 mbar. The variation with **hydrogen** is of the same size and also complies with NK 1. It was assumed that the response pressure of the VAK(AAN) was set at 180 mbar.

**Conclusions**:

- The variation in response pressure for the VAK(AAN) is approximately the same for **hydrogen** as it is for **natural gas**.

## 6.2 Leak tightness (internal) of activated safety devices – measurement number 3 and 5

### 6.2.1 Safety valve

For the VA section, see 4.1.1.

### 6.2.2 Safety shut-off valve

**Natural gas**

The average leakage value throughout the entire 15-minute period was 0.23 mbar/min. This equates to a leakage of 31.4 ± 10% mm³/s.

**Hydrogen**

The average leakage value throughout the entire 15-minute period was 0.45 mbar/min. This equates to a leakage of 60.0 ± 10% mm³/s.

During the measurements with the Fiorentini Dival 600, the connection between pressure sensor P2 and the gas station appeared to be leaking during the bubble solution process, and the leakage was clearly visible (see photo below). This leakage could not be repaired and may explain the high leakage values. The safety shut-off valve is expected to be leak tight.


*Figure 7: Leakage at pressure sensor connection P2*

Comments:

- For the acceptance criteria according to NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- The inlet valve complies with Rate C (3.0 * DN = 150 mm³/s).

**Conclusion**: the internal leak tightness of the safety shut-off valve meets the requirements.

## 6.3 Closing pressure when closing the control valve – measurement number 6

The closing pressure for the measurements on the Fiorentini Dival 600 are shown in Table 8.

*Table 8 – Closing pressures*

| Medium | Inlet pressure [bar] | Closing pressure*) [mbar] |
|---|---|---|
| Natural gas | 3 | 117 |
| | 3 | 121 |
| | | |
| Hydrogen | 3 | 107 |
| | 3 | 106 |

Comment:

- The differences in closing pressure may have been caused by speed variation when closing the manually operated control valve.

**Conclusion**: the closing pressure for **natural gas** (in the tests) is on average approximately 12 mbar higher than the closing pressure for **hydrogen**.

## 6.4 Control behaviour – measurement numbers 7 and 8

Figure 8 shows the result of the measurement with **natural gas** and Figure 9 show the result with **hydrogen**, where the flow rate was gradually increased for thirty seconds and then decreased again by thirty seconds. The measurement was performed twice in the same manner. The pressure in the grid (represented by the buffer tank) was lowered to 70 mbar to see how the regulator would open up further (and deliver more gas) to accommodate this. In the case of the Fiorentini Dival 600, a maximum flow rate of 220 $m^3{}_n$/h was reached which corresponds well to the expected capacity. It should be noted that the capacity of the Fiorentini Dival 600 is much higher than that of the other two spring loaded regulators. This valve was not tested to its maximum capacity. For the graphs from the second measurement, see Annex IX.

Based on a duplicate measurement for natural gas, the pattern is approximately the same, although the behaviour is somewhat erratic. The flow rate of around 220 $m^3{}_n$/h was achieved, which is in the lower range for the regulator. To mimic the demand from the grid, a pressure drop to 70 mbar was simulated. This value was not reached by the response (and capacity) of the regulator. The lowest pressure measured on the buffer tank was 80 mbar.

Based on the assigned regulation class (RK 5) for the Fiorentini Dival 600 regulator, the deviation falls within the bandwidth for this measurement.

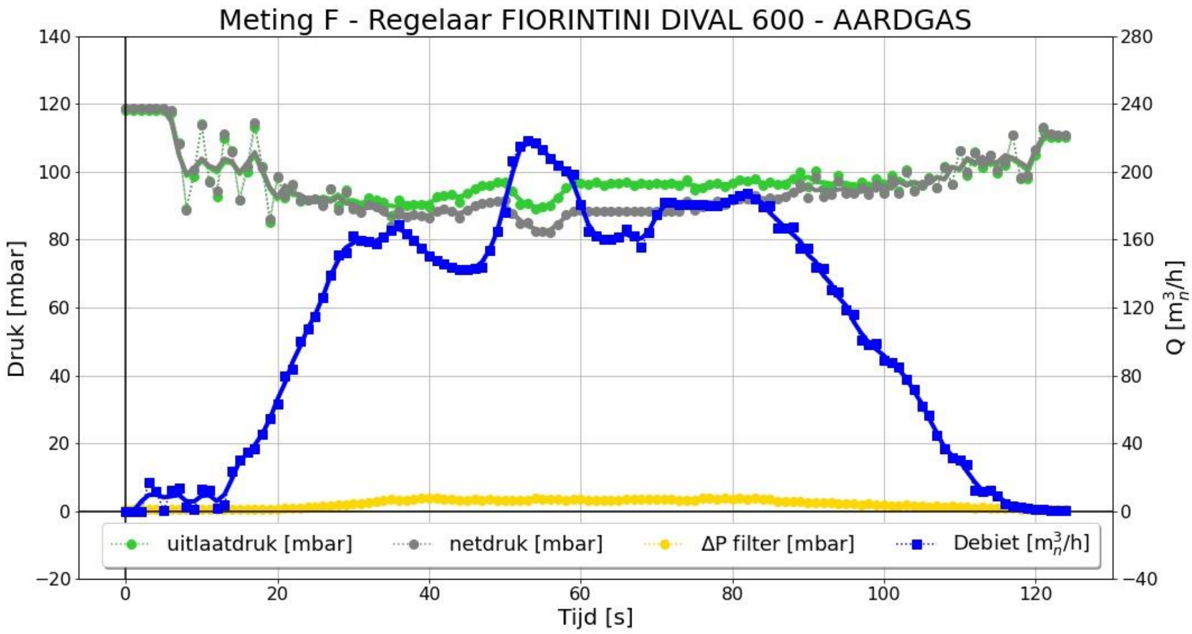


*Figure 8: Pressure stability with an increasing and decreasing flow rate – natural gas*

Explanation of the graph:

- The **blue** line is the flow rate converted to $m^3{}_n$/h, indicated on the secondary y-axis.
- The thick **orange** line is the measured pressure difference over the filter with 1 measurement per second. This pressure is measured in the 3 bar section, the maximum pressure drop over the filter is again about 4 mbar.
- The thick **green** line is the outlet pressure measured at the header of the station. This line is the average over 120 measurements (= 120 seconds).
- The **grey** line is the ‘net pressure’, the pressure measured per 1 second at the buffer tank DN 400.

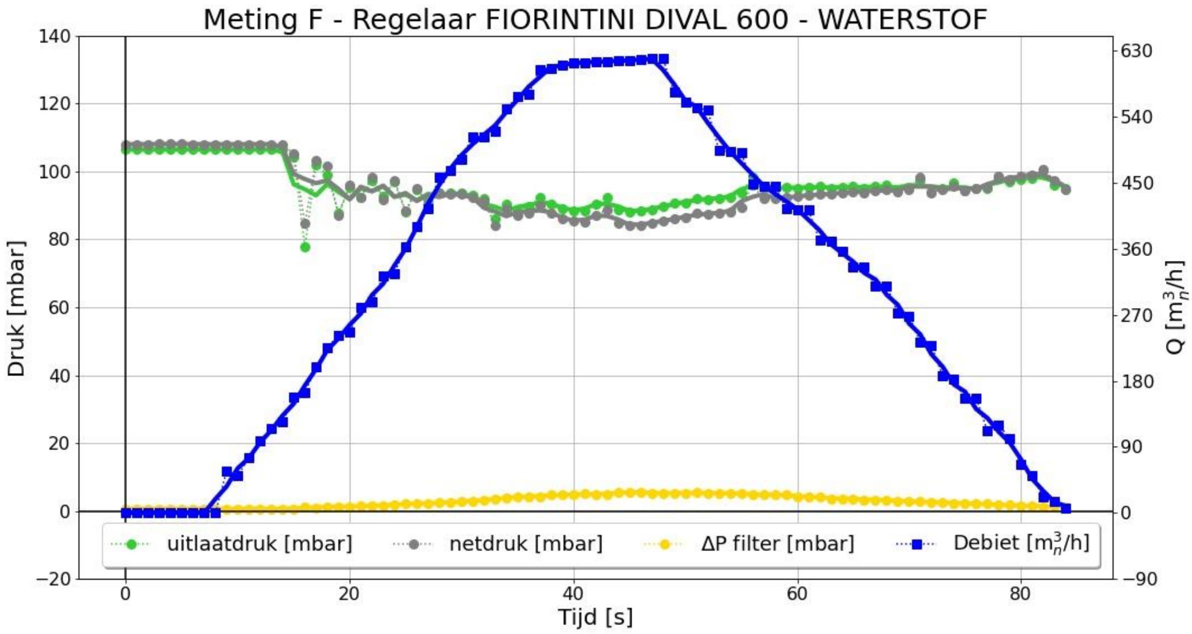


*Figure 9: Pressure stability with an increasing and decreasing flow rate – hydrogen*

Based on a duplicate measurement for hydrogen, the pattern is approximately the same. The maximum flow rate of over 600 $m^3_n/h$ is in line with expectations. To mimic the demand from the grid, a pressure drop to 70 mbar was simulated. This value was not reached by the response (and capacity) of the regulator. The lowest pressure measured on the buffer tank was over 80 mbar.

Based on the assigned regulation class (RK 5) for the Fiorentini Dival 600 regulator, the deviation falls within the bandwidth for this measurement.

Explanation of the graph:

- The thick **orange** line is the measured pressure difference over the filter with 1 measurement per second. This pressure was measured in the 3 bar section, the maximum pressure drop across the filter is approximately 5.5 mbar.
- For the explanation of the above figure, see Figure 8.

## 6.5 Noise emission

The noise emissions were measured both for **natural gas** and for **hydrogen**. The noise measurement was carried out with Bruel & Kjaer 2250 analyser, mounted on a tripod. The microphone of the sound meter was placed at a distance of one metre and at a height of one metre above the bottom of the cabinet.

In addition to the spectrum, this sound level meter measures the “surface weighted average” of the sound level spectrum, the so-called LAeq. As a result, short-lived, high measurements are not included in this average. According to the protocol, capacity measurements were carried out at 200 $m^3_n/h$ (=100%) **natural gas** and 600 $m^3_n/h$ (=100%) **hydrogen**.

During the measurement of the control behaviour with the Fiorentini Dival regulator, as described in section 6.4, an LAeq of 57.1 dB was measured for **natural gas**.

During the measurement of the control behaviour with the Fiorentini Dival regulator, as described in section 6.4, an LAeq of 59.6 dB was measured for **hydrogen**.

Comments:
The flow rate during the noise measurement corresponds to the intended flow rate in the measurement protocol. For natural gas, the measurement was carried out at 100% **natural gas**, which corresponds to 200 $m^3_n/h$, 100% **hydrogen** corresponds to 600 $m^3_n/h$).

It should be taken into account that components near the test setup also influenced the noise measurement. These effects were not filtered out.

**Conclusion**: the noise emission with the application of **hydrogen** (at a flow rate of 600 $m^3_n/h$) is 2.5 dB(A) higher than with **natural gas** (at a flow rate of 200 $m^3_n/h$).

## 6.7 Gas filter

During the measurements with both **natural gas** and **hydrogen**, the pressure drop over the filter housing (and gas filter) was logged over time. Before the start of the measurement with **natural gas**, the gas filter was visually inspected and pictures of the filter were taken. Subsequently, successive tests with **natural gas** and **hydrogen** were carried out for three regulators. After completion of this series, the gas filter was inspected again and photographs of the gas filter were taken. In the figure below, these photos are placed side by side.

The photos show that the filters have not been adversely affected during tests with natural gas or hydrogen. It should be noted that contamination causes an increase in the pressure drop over the filter, which can lead to degradation or even rupture of the filter.

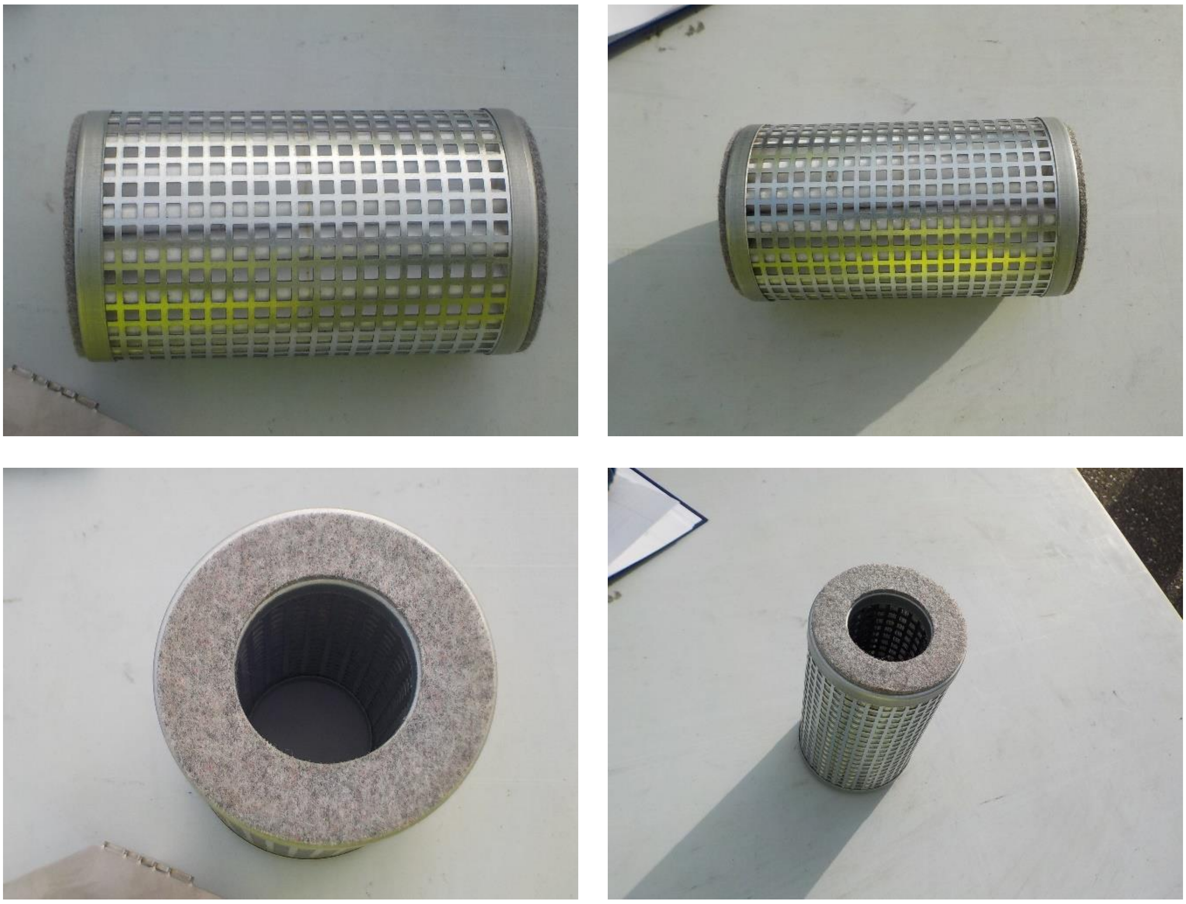

*Figure 10: Gas filter before the start of the tests with **natural gas** (left) and after completion of the tests with **hydrogen** (right)*

During the measurements with **natural gas** and **hydrogen**, the pressure drops across the filter in time were recorded as a function of the flow rate. Consistent use has been made of the measurements in which the control behaviour was mapped out. For **natural gas**, the maximum measured pressure drop across the filter was approximately 3 mbar at a flow rate of 180 $m^3_n$/h. Bij **hydrogen**, the maximum measured pressure drop across the filter was approximately 12 mbar at a flow rate of 700 $m^3_n$/h. This pressure drop is considerably higher for **hydrogen** than for **natural gas**.

Based on the above measurements, the relationship between pressure drop and flow rate with the other regulators was also examined. Smaller differences were found, which led to the assumption that the system (the gas station, the gas filter and the medium) all had an effect.

**Conclusion:** based on visual inspection and a closer examination, it was determined that the gas filter was not affected/damaged by the tests with **natural gas** and **hydrogen** as a result of the high velocities prevailing during these tests.

# 7. Measurement results – IGA1843 regulator

This chapter contains the measurement results of the measurements on the HAS equipped with the IGA1843 regulator. The measurement results are shown according to the measurement sequence and the test numbering as stated in the measurement protocol. During the measurements, the temperature averaged 9.2 degrees and no standard deviation was calculated. The temperature was only recorded twice during the day. All measurement results are included in Annex XII of this report.

## 7.1 Leak tightness (internal) – measurement number 1

The content of the section between the inlet valve and the outlet valve is approximately 1 $dm^3$. For the leak tightness calculations, other capacity values are also required. Thus the volume between the VAK and the VAK(AAN) is set at 0.5 $dm^3$, the volume between the VAK(AAN) and the outlet valve (yellow ball valve) at 0.5 $dm^3$ and the volume between the outlet valve (with flexible pipe) and the butterfly valve behind the pressure vessel at 219 $dm^3$.

### 7.1.1 Inlet valve (VAK)

**Natural gas**

The average leakage rate over the entire 15-minute period was 0.01 mbar/min. This equates to a leakage of 0.1 ± 10% $mm^3/s$.

**Hydrogen**

The average leakage rate over the entire 15-minute period was 0.09 mbar/min. This equates to a leakage of 0.6 ± 10% $mm^3/s$.

Comments:

- For the acceptance criteria according to NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- The inlet valve complies with Rate C (3.0 * DN = 150 $mm^3/s$).

**Conclusion**: the internal leak tightness of the inlet valve complies with the requirements.

## 7.2 Response pressure of safety devices – measurement number 2 and 4

The response pressures for the VAK and VAK(AAN) are indicated in the tables below.

*Table 9 – Response pressure and closing time VAK*

| Safety shut-off valve VAK – Set value is 160 mbar*) | |
|---|---|
| **Medium** | **Response pressure**) [mbar]** |
| Natural gas | 163 |
| | 162 |
| | 161 |
| | |
| Hydrogen | 164 |
| | 162 |
| | 160 |

*) The safety devices are set according to the pressure readings on the analogue pressure gauges in the gas line concerned. This involves a degree of inaccuracy as compared to the digital pressure gauges during the tests. Given the (average) measuring results for natural gas, a set value for the VA of 160 mbar was assumed.

*Table 10 – Response pressure VAK(AAN)*

| Safety shut-off valve VAK(AAN) - Set value is 200 mbar*) | |
|---|---|
| **Medium** | **Response pressure [mbar]** |
| Natural gas | 200 |
| | 195 |
| | 195 |
| | |
| Hydrogen | 199 |
| | 197 |
| | 201 |

*) The safety devices are set according to the pressure readings on the pressure gauge of the gas line concerned. This involves a degree of inaccuracy with respect to the calibrated pressure gauge during the tests. Given the (average) measuring results for natural gas, a set value for the VAK(AAN) of 195 mbar is assumed.

Table 9 shows that the response pressure for the VAK with natural gas is fairly constant at around 160 mbar. This complies with the criteria of NK 2.5 (permissible deviation ± 4.0 mbar). With **hydrogen**, the response pressure also hardly varies; the measured values are between 160 and 164 mbar. The variation with **hydrogen** is of the same size and also complies with NK 2.5. It was assumed that the VAK response pressure was set at 160 mbar.

Table 10 - shows that the VAK(AAN) response pressure for natural gas ranges between 195 and 200 mbar. This complies with the criteria of NK 2.5 (permissible deviation ± 5 mbar). With **hydrogen**, the response pressure varies between 197 and 201 mbar. The variation with **hydrogen** is of the same size and also complies with NK 1. It was assumed that the response pressure of the VAK(AAN) was set at 200 mbar.

**Conclusions**:

- The variation in response pressure the VAK as well as the VAK(AAN) with **hydrogen** is approximately equal to that of natural gas.

## 7.3 Leak tightness (internal) of activated safety devices – measurement number 3 and 5

### 7.3.1 Safety shut-off valve (VAK(AAN))

**Natural gas**
The average leakage rate over the entire 15-minute period was 0.0 mbar/min. This equates to a leakage of 0.0 ± 10% mm³/s.

**Hydrogen**
The average leakage rate over the entire 15-minute period was 0.01 mbar/min. This equates to a leakage of 0.1 ± 10% mm³/s.

Comments:

- For the acceptance criteria in accordance with NEN-EN12266-1-2012 and the calculation of the internal leakage, see Annex VI.
- The inlet valve complies with Rate C (3.0 * DN = 150 mm³/s).

**Conclusion**: the internal leak tightness of the safety shut-off valve meets the requirements.

## 7.4 Closing pressure when closing the control valve – measurement number 6

The closing pressure for the measurements on the IGA1843 regulator are shown in Table 11.

*Table 11 – Closing pressures*

| Medium | Inlet pressure [bar] | Closing pressure*) [mbar] |
|---|---|---|
| Natural gas | 3 | 100.2 |
| | 3 | 100.4 |
| | | |
| Hydrogen | 3 | 99.1 |
| | 3 | 99.1 |

**Conclusion:** the closing pressure (in the tests) with **natural gas** is virtually the same as the closing pressure with **hydrogen**.

## 7.5 Control behaviour – measurement number 7 and 8

Figure 11 shows the result of the measurement with **natural gas** and Figure 12 shows the result with **hydrogen** where the flow rate was gradually increased for seventy-five seconds, held constant at the maximum flow rate for sixty seconds and then reduced again by seventy-five seconds. The measurement was carried out three times in a row.

In the case of the high pressure delivery station, the buffer tank was not used. On the outlet side, a flexible hose was installed, which was connected to the flow meter. Downstream of the flow meter, a steel pipe with a length of about 10D was installed. A motorised valve with a smaller diameter than in the earlier tests was connected to this. This is because of the small range of the high pressure delivery station.

During the test, the pressure on the downstream side of the high pressure delivery station was lowered to 70 mbar to check how the regulator opens up further (and deliver more gas) to accommodate this. In the case of the IGA1843, a maximum flow rate of 30 $m^3_n/h$ **natural gas** is reached which corresponds well to the expected capacity. See Annex X for the graphs from the second measurement in which a step-by-step build-up to the maximum flow rate was measured. This experiment was carried out twice in a row.

No regulation class could be found for the IGA1843, so it cannot be determined whether it is adequate for this measurement.

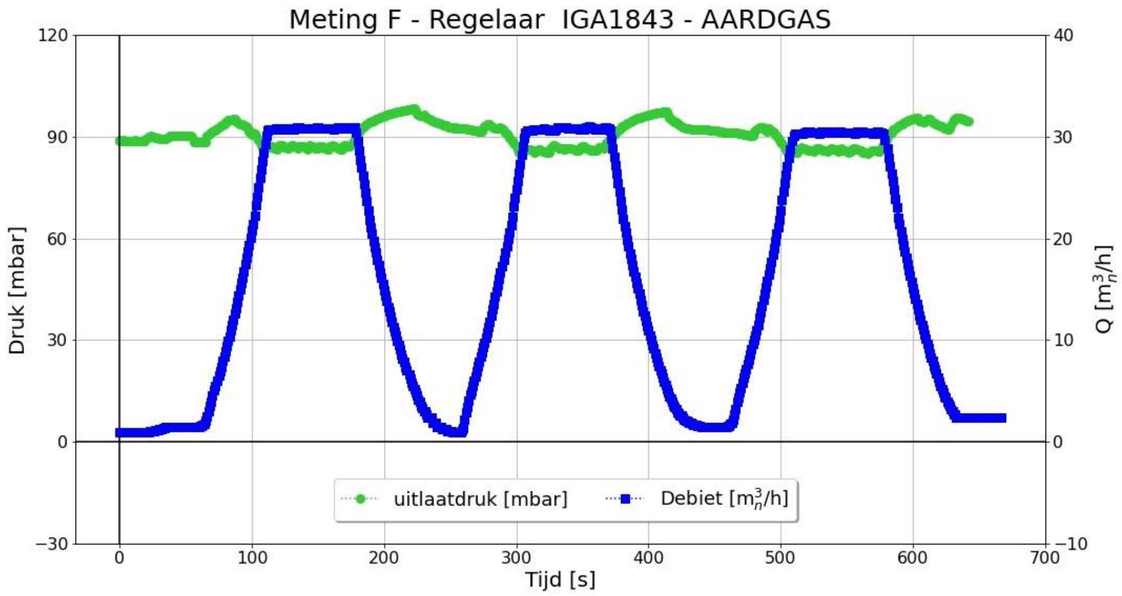


*Figure 11: Pressure stability with an increasing and decreasing flow rate – natural gas*

<u>Explanation of the graph:</u>

- The **blue** line is the flow rate converted to $m^3_n/h$, indicated on the secondary y-axis.
- The thick **green** line is the outlet pressure measured at the header of the station. This line is the average over 650 measurements (= 650 seconds).

During the test, the pressure on the downstream side of the high pressure delivery station was lowered to 70 mbar to check how the regulator opens up further (and deliver more gas) to accommodate this. In the case of the IGA1843 a maximum flow rate of 90 $m^3_n$/h **hydrogen** which is well in line with the expected capacity. See Annex X for the graphs from the second measurement in which a step-by-step build-up to the maximum flow rate was measured. This experiment was carried out twice in a row.

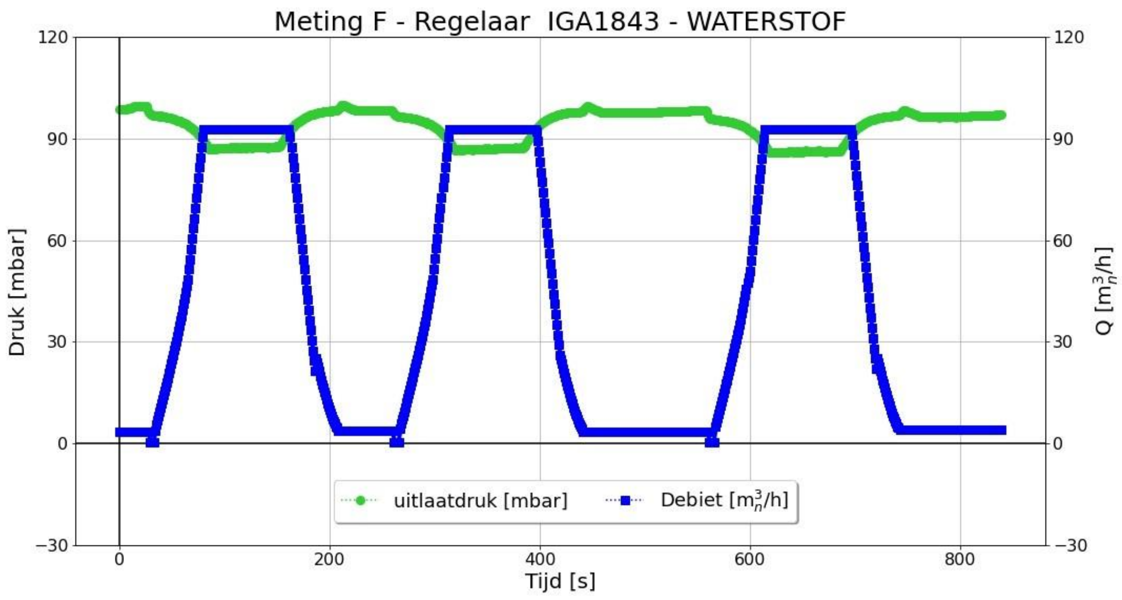


*Figure 12: Pressure stability with an increasing and decreasing flow rate – hydrogen*

Explanation of the graph:

- For the explanation of the above figure, see Figure 11.

**Conclusions**:

- The pressure stability was not (adversely) affected by the application of **hydrogen**.

## 7.6 Noise emission

The noise emissions were measured both for **natural gas** and for **hydrogen**. The noise measurement was carried out with a Bruel & Kjaer 2250 analyser mounted on a tripod. The microphone of the noise meter was placed at a distance of one metre from the high pressure delivery station at a height of one metre above the base of the installation.

In addition to the spectrum, this sound meter measures the “surface weighted average” of the sound level spectrum, the so-called LAeq. As a result, short-lived, high measurements are not included in this average.

During the measurement of the control behaviour with the IGA1843 regulator, as described in paragraph 7.5, an LAeq of 62.1 dB was measured for **natural gas**.

During the measurement of the control behaviour with the IGA1843 regulator, as described in section 7.5, an LAeq of 62.6 dB was measured for **hydrogen**.

Virtually no difference in noise levels was observed during the noise measurements with natural gas and hydrogen for the high pressure delivery station.

Comments:

- The flow rate is indicated in a percentage (100% **natural gas** corresponds to 30 $m^3_n$/h, 100% **hydrogen** corresponds to 90 $m^3_n$/h).
- By repeating the experiments for the high pressure delivery station, the exact intended capacity was reached by using a smaller motorised valve.
- It should be taken into account that components near the test setup also influenced the noise measurement. These effects were not filtered out.

**Conclusion**: the noise emission with the application of **hydrogen** (at a flow rate of 90 $m^3_n/h$) is 0.5 dB(A) higher than with **natural gas** (at a flow rate of 30 $m^3_n/h$). This is the same based on the average.

## 7.7 Gas filter

During the measurements with both **natural gas** and **hydrogen**, the pressure drop over the filter housing (and gas filter) was logged over time. Before the start of the measurement with **natural gas**, the gas filter was visually inspected and pictures of the filter were taken. Subsequently, the tests with **natural gas** and **hydrogen** were carried out. After completion of this series, the gas filter was inspected again and photographs of the gas filter were taken. In the figure below, these photos are placed side by side.

*Figure 13: Gas filter before the start of the tests with **natural gas** (left) and after completion of the tests with **hydrogen** (right)*

During the measurements with **natural gas** and **hydrogen**, the values for the pressure drop across the filter could not be recorded because the necessary connections were not present on the HAS.

**Conclusion:** based on visual inspection and a closer examination, it was determined that the gas filter was not affected/damaged by the tests with **natural gas** and **hydrogen** as a result of the high velocities prevailing during these tests.

# Conclusions

Based on the measurements as presented in this report, the main conclusion is as follows:

The gas pressure regulator station tested, which was designed for **natural gas**, can be used for **hydrogen** without any modifications. The gas pressure regulators tested also show only minor differences when the medium of **natural gas** or **hydrogen** is applied respectively.

The conclusion above can also be drawn for the high pressure delivery station. Here too, only minor differences can be seen when either **natural gas** or **hydrogen** is used.

Comment:

- This conclusion only concerns technical functionality. No statement can be made about the long-term effects.

The sub-conclusions are summarised in Table 12 and Table 12.

*Table 12 – Sub-conclusions (Itron 233 regulator and Elster Instromet 243 regulator)*

| Topic | Itron 233 | | Elster Instromet 243 | | Comment |
|---|---|---|---|---|---|
| | Natural gas | Hydrogen | Natural gas | Hydrogen | |
| Leak tightness external control set | 0 | 0 | 0 * | 0 * | |
| Leak tightness internal control set | 0 | 0 | 0 * | 0 * | |
| Pressure loss over filter | 0 | 0 | 0 * | 0 * | Indicative measurement |
| Response pressure VA and VAK | 0 | 0 | 0 | 0 | Medium has no effect |
| Closing time VA | 0 | 0 | 0 | 0 | Medium has no effect |
| Leak tightness internal VA and VAK | 0 | 0 | 0 | 0 | |
| Closing pressure | 0 | 0 | 0 | - | Difference possibly caused by variation in closing speed of the manually operated control valve |
| Pressure stability | 0 | 0 | 0 | 0 | |
| Noise emission | 0 | + | 0 | - | |
| Control behaviour | 0 | 0 | 0 | 0 | Relative to target capacity |

Explanation:

- If the measuring results with **hydrogen** are (almost) the same as with **natural gas** this is indicated by a '0'.
- If the measuring results with **hydrogen** are more favourable than with **natural gas**, this is indicated by a '+'. If they are less favourable, then this is indicated by a '-'.
- All items marked with '*' have already been tested for the Itron 233 configuration. The regulators were checked after installation using a bubble solution to demonstrate the tightness of the configuration.

*Table 13 - Sub-conclusions (Fiorentini Dival 600 regulator and IGA1843 regulator)*

| Topic | Dival 600 | | IGA 1843 | | Comment |
|---|---|---|---|---|---|
| | Natural gas | Hydrogen | Natural gas | Hydrogen | |
| Leak tightness external control set | N/A | N/A | 0 | 0 | |
| Leak tightness internal control set | N/A | N/A | 0 | 0 | |
| Pressure loss over filter | N/A | N/A | 0 | 0 | Indicative measurement |
| Response pressure VA and VAK | 0 | 0 | 0 | 0 | Medium has no effect |
| Closing time VA | 0 | 0 | 0 | 0 | Medium has no effect |
| Leak tightness internal VA and VAK | 0 | 0 | 0 | 0 | |
| Closing pressure | 0 | - | 0 | - | Difference possibly caused by variation in closing speed of the manually operated control valve |
| Pressure stability | 0 | 0 | 0 | 0 | |
| Noise emission | 0 | - | 0 | 0 | |
| Control behaviour | 0 | 0 | 0 | 0 | |

Explanation:

- If the measuring results with **hydrogen** are (almost) the same as with **natural gas** this is indicated by a ‘0’.
- If the measuring results with **hydrogen** are more favourable than with **natural gas**, this is indicated by a ‘+’. If they are less favourable, then this is indicated by a ‘-’.

# Recommendations

In the context of this HyDelta work package, research has been conducted into a selection of the most common regulators used in gas stations. In order to gain long-term experience, it may be useful to carry out pilot projects with the most common gas stations. It is recommended that the capacity of the station and the regulator are matched so that the total measurement range can be tested. It is also advisable to examine the regulation class for the regulators for both natural gas and hydrogen.

A proposal for testing gas filters is to make a comparison between natural gas and hydrogen with dust. For this purpose, in the lead-up to HyDelta 2.0, a proposal was written for testing gas filters at 8 bar. The objective of these tests is to demonstrate whether gas filters with natural gas and hydrogen collect the same amount of dust. The amount of dust is a specific focus point.

# References

[1] IEEE, “IEEE Citation Guidelines,” [Online]. Available: https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf. [Accessed 19 03 2021].

[2] Zenodo, “Terms of Use v1.2,” Zenodo, [Online]. Available: https://about.zenodo.org/terms/. [Accessed 19 03 2021].

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# I Overview of questions HyDelta WP1B

This work package addresses the following questions

Material resistance:

- Can the soft components of the regulators and safety devices used in natural gas distribution be adversely affected when switching to hydrogen distribution? (no. 207, see KIWA report GT-200237)

Operation of the station:

- Are the current stations suitable for safely reducing hydrogen gas (the station as a whole)? (no. 206, see HyDelta report - D1B.1 - Gas pressure regulators on natural gas and hydrogen)
- What effects does increasing the speed have on the overall operation of the station? (no. 213, see HyDelta report - D1B.1 - Gas pressure regulators on natural gas and hydrogen)
- Are adjustments to the housing necessary in order to safely use H2 and, if so, which ones? (ventilation & earthing) (no. 212, see HyDelta report - D1B.4 - Ventilation)

Working safely on and with stations using hydrogen:

- What mitigating measures (VWI) are necessary to commission and decommission a station? (no. 208, see HyDelta Report - D1B.2 - Safety when working on gas stations)
- Is it possible to safely equalise the pressure if a safety device has failed? (no. 209, part of 208, see HyDelta Report - D1B.2 - Safety when working on gas stations)
- Is there a need for a more thorough inspection of filters in gas pressure regulators? This section is specifically about filters; the increased gas velocity can lead to more dirt being transported, which can lead to increased stress on the filters (no. 173, see HyDelta report - D1B.4 - Gas filters)

# II Overview of the guidance and sparring group

*Table 14 – Members of the guidance group and sparring group*

| Name | Affliation | Guidance group | Sparring group |
|---|---|---|---|
| R. van Hooijdonk | Enexis | V | V |
| J. Jonkman | RENDO | V | V |
| R. Scholten | RENDO | V | V |
| P. Verstegen | Alliander | V | V |
| R. Verhoeve | Stedin | | V |
| J. Voogt | Enexis | | V |
| S.J. Elgersma | Gasunie | | V |
| M. van der Laan | Kiwa Technology | V | V |
| S. van Woudenberg | Kiwa Technology | V | V |
| *The guidance group has been assigned a more active role in implementing the sub-research as compared to the sparring group. The sparring group was involved in setting up the test programme and in assessing the draft reports.* | | | |

# III List of terms

| Term | Description / explanation |
| --- | --- |
| $L_{gas}$ (low calorific gas) | 86 vol% methane + 14% nitrogen |
| Overpressure | Pressure above atmospheric pressure<br>(8 bar corresponds to 9 bar absolute) |
| $m^3_n$ | One $m^3$ at 1,013.25 mbar(a) and 0 $^0$C |
| DS | District station |
| HAS | High pressure delivery station |
| VA | Safety valve |
| VAK | Safety shut-off valve |
| VAK(AAN) | VAK mounted on a regulator |
| $CH_4$ | Methane |
| $H_2$ | Hydrogen.<br>The tests were conducted using hydrogen 5.0 (purity 99.999%) |
| PLEXOR | Test kit for performing functional tests of gas stations |
| Regulation class (RK) | The maximum deviation (in absolute terms) between the desired and the occurring outlet pressure, expressed in percentage of the desired value |
| Closing pressure | Outlet pressure of the regulator at zero supply flow rate |
| Closing pressure class (SK) | Maximum pressure increase in per cent as compared to nominal output pressure that can occur when the supply flow rate is reduced to zero |
| Accuracy class (NK) | The accuracy at which the command valve of the VA or a VAK(AAN) activates. |

# IV Components used in gas pressure regulating station(s)

District station used in the test programme

## Gegevens toegepaste componenten

gAvilar *goed geregeld!*

### Gegevens opdrachtgever:

| | | | |
|---|---|---|---|
| Opdrachtgever: | Enexis | Artikelnummer opdrachtgever: | 74345 |
| Opdrachtnummer: | 4500763600 | Ingangsdatum: | 15-mei-19 |
| Contactpersoon: | J. Murkens | Telefoon: | 0 |

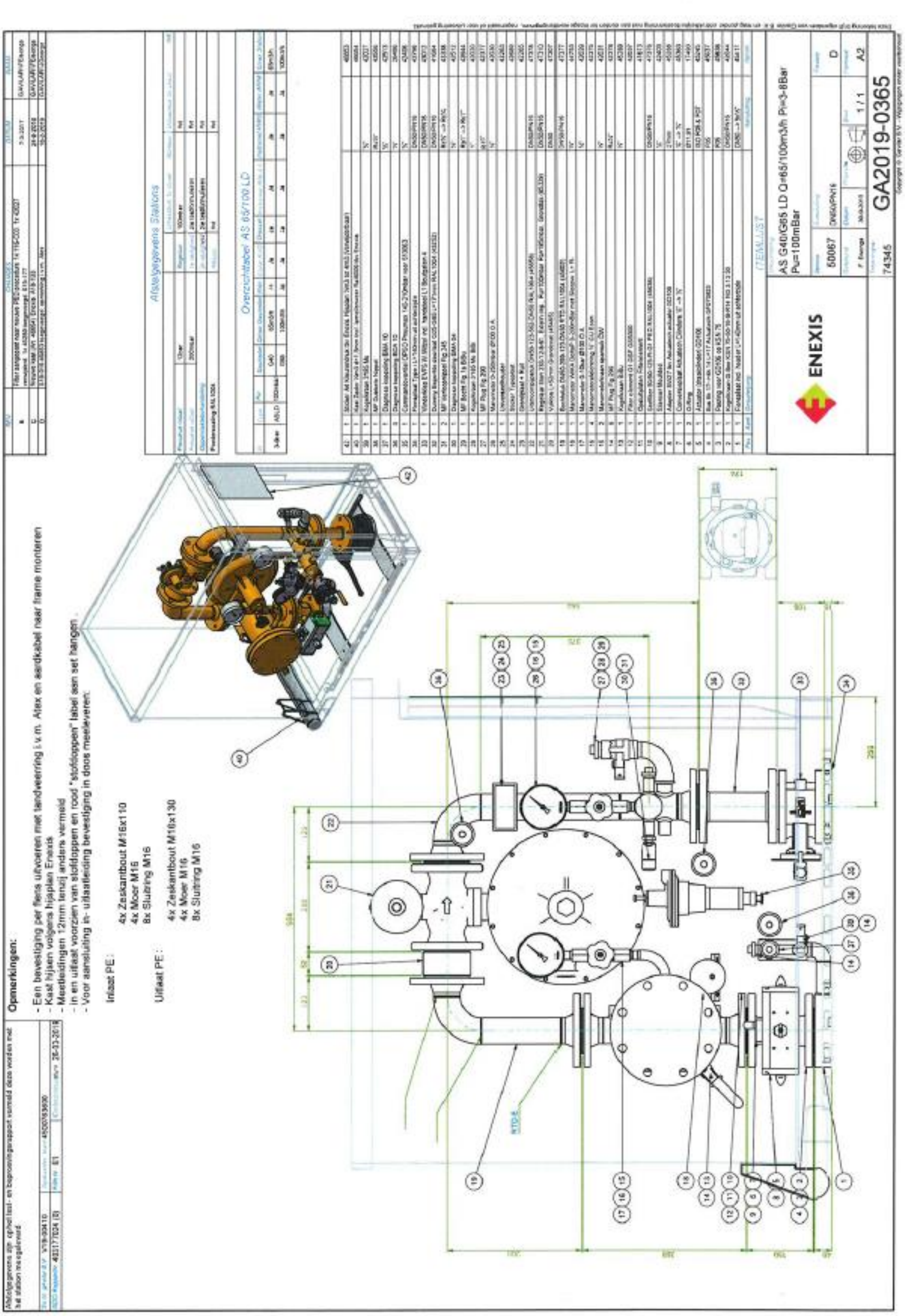
### Gegevens installatie:

| | | | |
|---|---|---|---|
| Omschrijving: | AS G40/65 LD Pi= 3 - 8 bar Pu= 100 mbar | | |
| Serienummer: | **GA2019-0365** | Pi max. : | 8 barg |
| Itemnummer gAvilar: | 50067 | Pi min. : | 3,00 barg |
| Tekeningnummer: | S- 50067 | Pu werk: | 100 mbar |
| SO-nummer gAvilar: | V19-00410 | Capaciteit: | 65/100 $Nm^3/h$ |

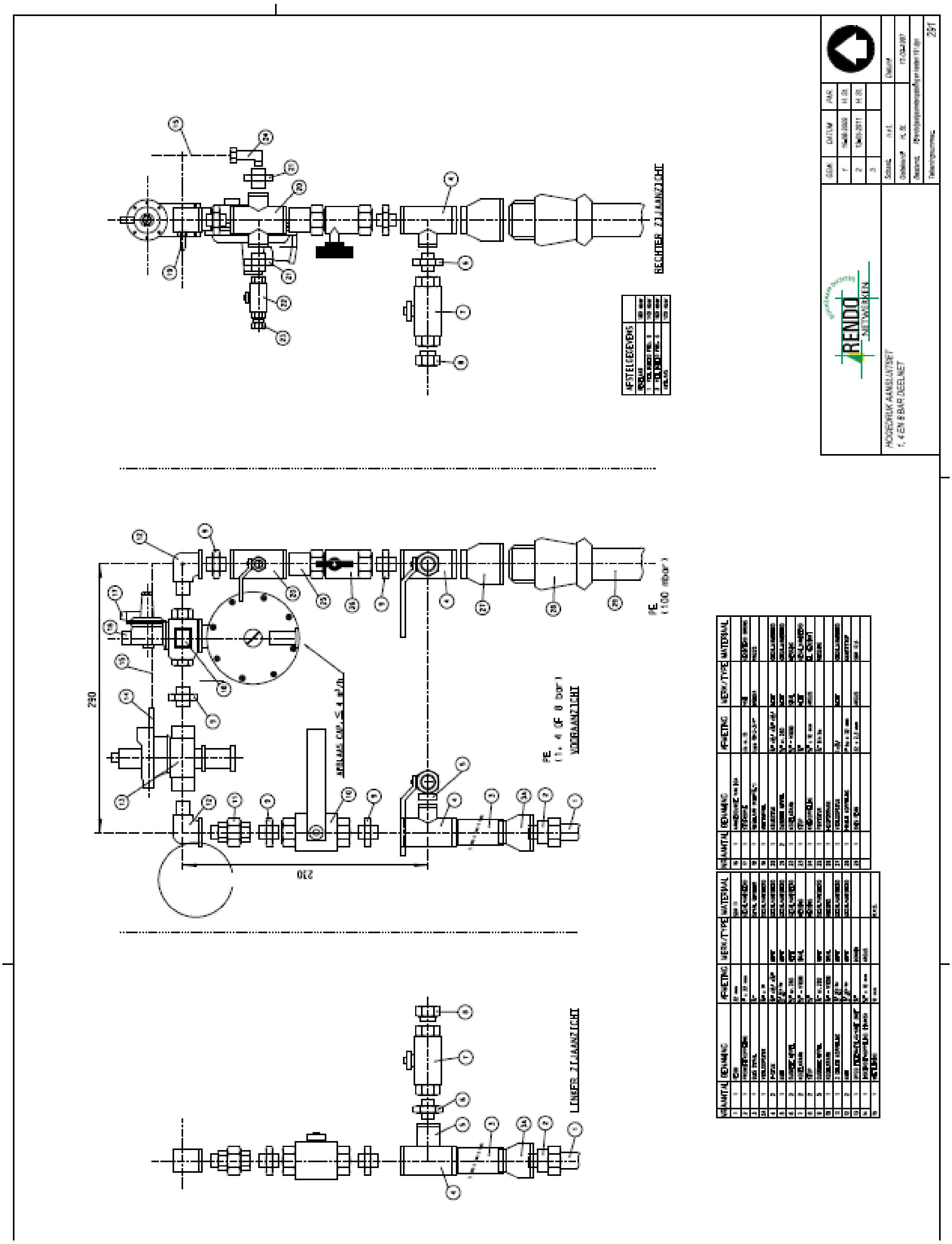
| Component | Art. nummer | Omschrijving | Serienummer |
|---|---|---|---|
| Afsluiter inlaat | 42044 | Kogelkraan G-Bee KS75 DN50 PN16 STD | |
| Draaicilinder | 45245 | Draaicilinder Actuatech GD106 | |
| Commandoventiel | 42406 | Commandoventiel Opso-Pneumax bereik 140 - 210 mbar | 102237-10 |
| 2e veiligheid VA | 42296 | Veiligheidsafslagcombinatie bestaande uit bovenstaande items | |
| Stoffilter | 47376 | Stoffilter DN50/125-R-G1 1 x RTD (45638) | 45638-006 |
| Filterelement | 42037 | Filterelement GS 5000 165-94x049 G1 | |
| Manometer ΔP | 43550 | Manometer Δp bereik 0 - 200 mbar met sleepwijzer | |
| Manometer Pi | 42029 | Manometer 0-10 bar kast 100mm RVS 1/2" | |
| Gasmeter | n.v.t. | n.v.t. | |
| Dummy | 41664 | Passtuk t.b.v. G25/40/65 gasm. DN50 L = 171 mm blind (43252) | |
| Regelaar | 41912 | Itron 233-12-8-62 DN50 Pu = 100 mbar kl 3/8" uitw.in (85108) | |
| Pilot regelaar | | serienummer vermelden indien van toepassing | |
| 1e veiligheid VAK | 41912 | Itron 233-12-8-62 DN50 Pu = 100 mbar kl 3/8" uitw.in (85108) | 3463401875 |
| Afblaas VAF | n.v.t. | n.v.t. | |
| Manometer Pu | 42030 | Manometer 0-250 mbar kast 100mm RVS 1/2" | |
| Diverse 1 | n.v.t. | n.v.t. | |
| Diverse 2 | 26496 | Kamstrup ventiel-diagnose 3/2 1/4" BDA10 | |
| Diverse 3 | 42515 | | |
| Diverse 4 | n.v.t. | n.v.t. | |
| Afsluiter uitlaat | 42798 | Vlinderklep WW type EVFS DN100-PN16 incl.handsteel | |
| Behuizing | 46654 | Kantelkast 1/2 m3 d = 1,5 mm + z.i. + t.o. Ral 6009 fabr. Zador | |
| Inlaatleiding | n.v.t. | n.v.t. | |
| Uitlaatleiding | n.v.t. | n.v.t. | |

| Verzendgereed maken: | |
|---|---|
| Controle ademopeningen: | Ja / ~~Nee~~ / ~~N.v.t.~~ |
| Sticker roken en vuur op kast: | Ja / ~~Nee~~ / ~~N.v.t.~~ |
| Typeplaat juist ingevuld: | Ja / ~~Nee~~ / ~~N.v.t.~~ |
| Onderzoeksrapport röntgentechnisch onderzoek meegeleverd: | Ja / ~~Nee~~ / ~~N.v.t.~~ |
| Olie voor rotorgasmeter meegeleverd: | ~~Ja~~ / ~~Nee~~ / N.v.t. |
| Bouten, moeren, sluitringen en pakkingen meegeleverd: | Ja / ~~Nee~~ / ~~N.v.t.~~ |
| Opmerkingen: X | |

| | |
|---|---|
| nummer: | 21-G-3.703 |
| versie: | b |
| datum | 12-2-2019 |


Opmerkingen:
- Een bevestiging per flens uitvoeren met tandveerring i.v.m. Atex en aardkabel naar frame monteren
- Kast hijsen volgens hijsplan Enexis
- Meetleidingen 12mm tenzij anders vermeld
- In en uitlaat voorzien van stofdoppen en rood "stofdoppen" label aan set hangen
- Voor aansluiting in- uitlaatleiding bevestiging in doos meeleveren:
Inlaat PE:
4x Zeskantbout M16x110
4x Moer M16
8x Sluitring M16
Uitlaat PE:
4x Zeskantbout M16x130
4x Moer M16
8x Sluitring M16
Afstelgegevens Stations
Overzichtstabel AS 65/100 LD
ENEXIS
AS G40/G65 LD Q=65/100m3/h Pi=3-8Bar
Pu=100mBar
GA2019-0365

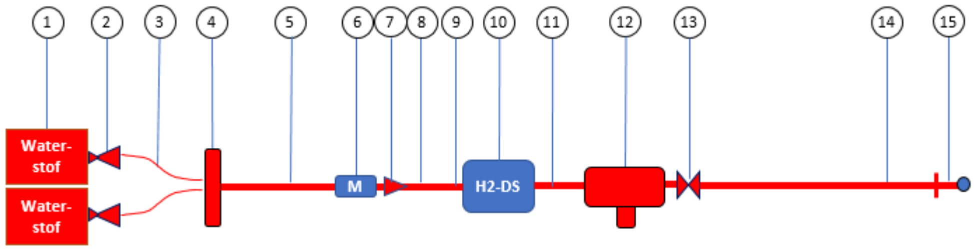
High pressure delivery station (HAS) used in test programme



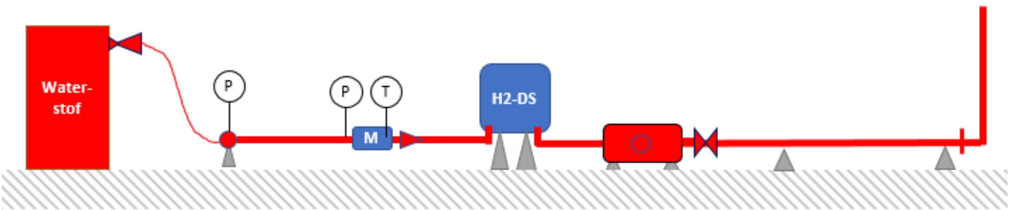
# V Diagram of test setup

A schematic representation of the test setup is shown below with the designation of the various components.

Top view




Side view

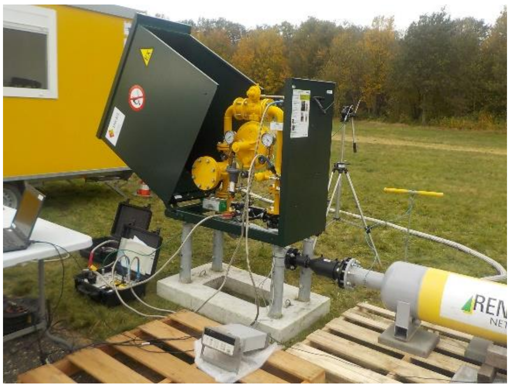



| Pos nr. | Aantal | Omschrijving |
|---|---|---|
| 1 | 2 | Flessenpakket H2 of (CH4) |
| 2 | 2 | Reduceer - 200 bar - 8 bar - DN 25 (1") |
| 3 | 2 | Slangen DN 25 (1") |
| 4 | 1 | Manifold DN 100 met 4 DN 25 (1") draadaansl. en DN 100 flensaansl.- PN 16 |
| 5 | 1 | Pijpstuk DN 100 - PN 16 - L = 12 m |
| 6 | 1 | Rotormeter G250 met EVHI / Mass Flow Meter |
| 7 | 1 | Verloop DN 100 - DN 50 |
| 8 | 1 | Slang met flenzen DN 50 |
| 9 | 1 | Stalen bocht DN 50 met flensaansl. - PN 16 |
| 10 | 1 | H2-DS |
| 11 | 1 | Stalen uitlaatpijpstuk DN 100 - PN 16 - L = 1 m |
| 12 | 1 | Stalen buffervat DN 400 L = 1,7 m - met header DN 50 met meetnippel 1/4" BSP |
| 13 | 1 | Regelafsluiter DN 100 - PN 16 |
| 14 | 1 | PVC uitlaatleiding DN 100 - L = 50 m |
| 15 | 1 | Stalen afblaaspijp DN 100 met ondersteuning en mogelijkheid tot aarden |

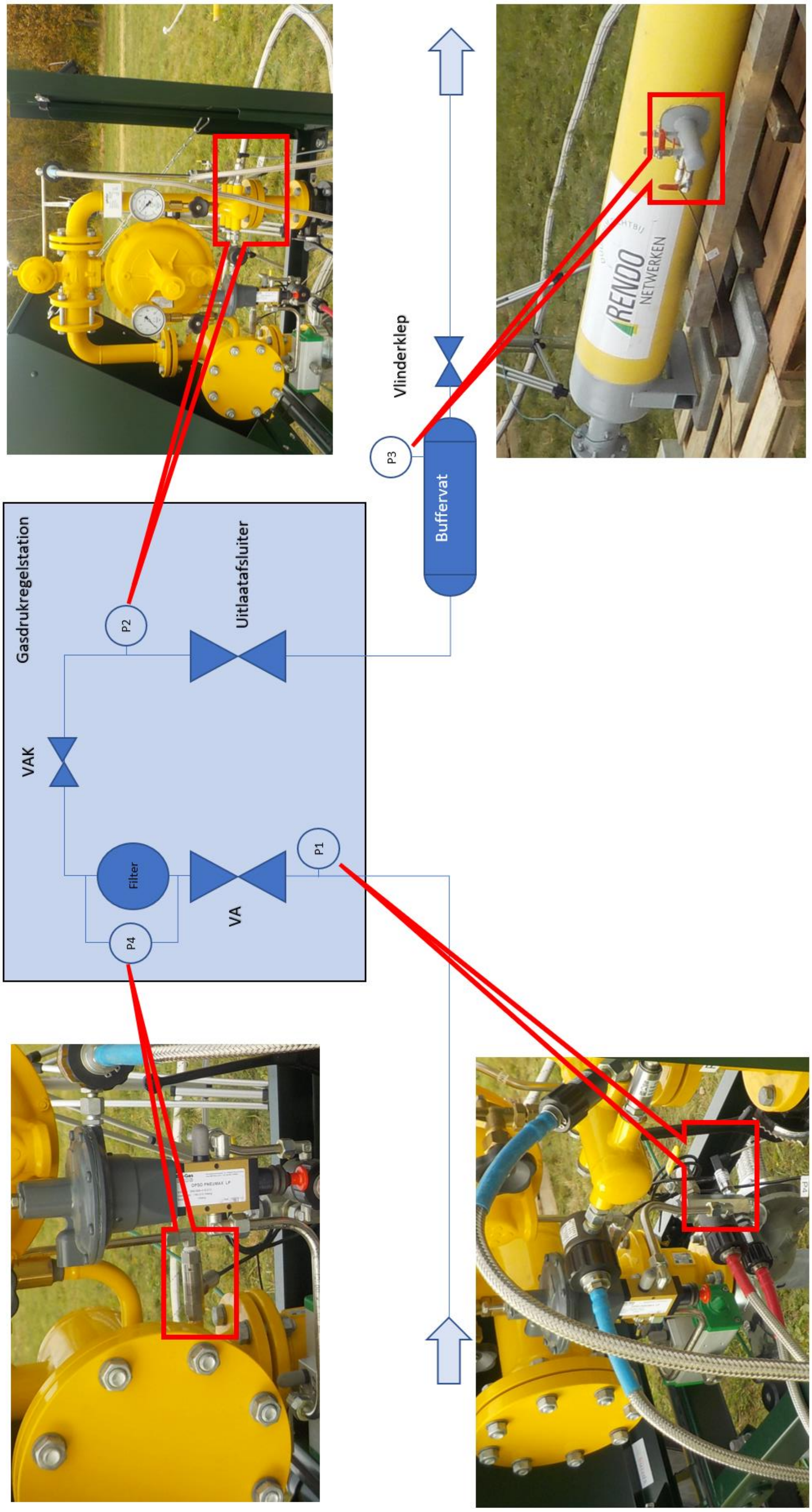
<u>Comment</u>:

- The capacity of the buffer tank (item no. 12) is approx. 0.2 m$^3$. EN 334 specifies that the closing pressure is to be determined using a pipe length of 10 x DN, where DN is the outlet diameter of the regulator. Because the majority of the tests will be done with a district station, it was decided to use a larger size.

Below are a few pictures of the test setup during the test phase at TSC.




The overview below has been added to clarify the location of the pressure sensors



# VI Calculation of valve leakage

This annex contains a table with the acceptance criteria (Table A.5) from NEN-EN12266-1-2012 *Industrial valves - Testing of metallic valves - Part 1: Pressure tests, test procedures and acceptance criteria - Mandatory requirements*.

Scope of the standard:
*This European standard specifies requirements for tests, test procedures and acceptance criteria for the production testing of metallic industrial valves. The specified tests can also be used as type tests or acceptance tests.*

In addition, leakage calculations for an inlet valve (gas pressure regulating station) and a safety shut-off valve are included.

**Table A.5 — Maximum allowable seat leakage for each leakage rate**

Unit: $mm^3/s$

| Test fluid | Rate A | Rate B | Rate C | Rate D | Rate E | Rate F | Rate G |
|---|---|---|---|---|---|---|---|
| Liquid | No visually detectable leakage for the duration of the test | 0,01 × DN | 0,03 × DN | 0,1 × DN | 0,3 × DN | 1,0 × DN | 2,0 × DN |
| Gas | | 0,3 × DN | 3,0 × DN | 30 × DN | 300 × DN | 3 000 × DN | 6 000 × DN |

NOTE 1 The leakage rates only apply when discharging to room temperature.

NOTE 2 Table A.1 shall be used to establish the equivalent DN number for those valves which are designated other than by DN.

NOTE 3 "No visually detectable leakage" means no visible weeping or formation of drops or bubbles. If leakage rate measurements are carried out by automatics means, this should be qualified by the manufacturer's quality system.

Calculation of internal leak tightness of the inlet valve for **natural gas**. The atmospheric pressure during the measuring period was set at 1010 hPa.

| | |
|---|---|
| P start = | 87.7 mbar |
| P end = | 85.3 mbar |
| Capacity* = | 15.53 $dm^3$ |

* This is the volumetric content of the control set from inlet valve to outlet valve.

$$Internal\ leakage\ = \frac{1097.7 * 15,53}{1095,3} - 15.53 = \ 0,077\ dm^3\ /\ 900\ s = 37,8\ mm^3/s$$

Calculation of internal leak tightness of the exhaust valve with **natural gas**. The atmospheric pressure during the measuring period was set at 1010 hPa.

P start = 87.7 mbar

P end = 84.6 mbar

Capacity** = 8.80 $dm^3$

** This is the volume between the VAK and the outlet valve of the control set.

$$Internal\ leakage\ = 8{,}80 - \frac{1097{,}7 * 8{,}80}{1094{,}6} = \ 0{,}0805\ dm^3\ /\ 900\ s = 27{,}7\ mm^3/s$$

Calculation of internal gas tightness of the exhaust valve with **hydrogen**.

P start = 86.6 mbar

P end = 84.5 mbar

Capacity* = 15.53 $dm^3$

* This is the content of the control set from inlet valve to outlet valve.

$$Internal\ leakage\ = \frac{1096{,}6 * 15{,}53}{1094{,}5} - 15{,}53 = \ 0{,}0674\ dm^3\ /\ 900\ s = 33{,}1\ mm^3/s$$

Calculation of internal leak tightness of the exhaust valve with **hydrogen**. This test was performed in 10 minutes instead of the usual 15 minutes.

P start = 0.1 mbar

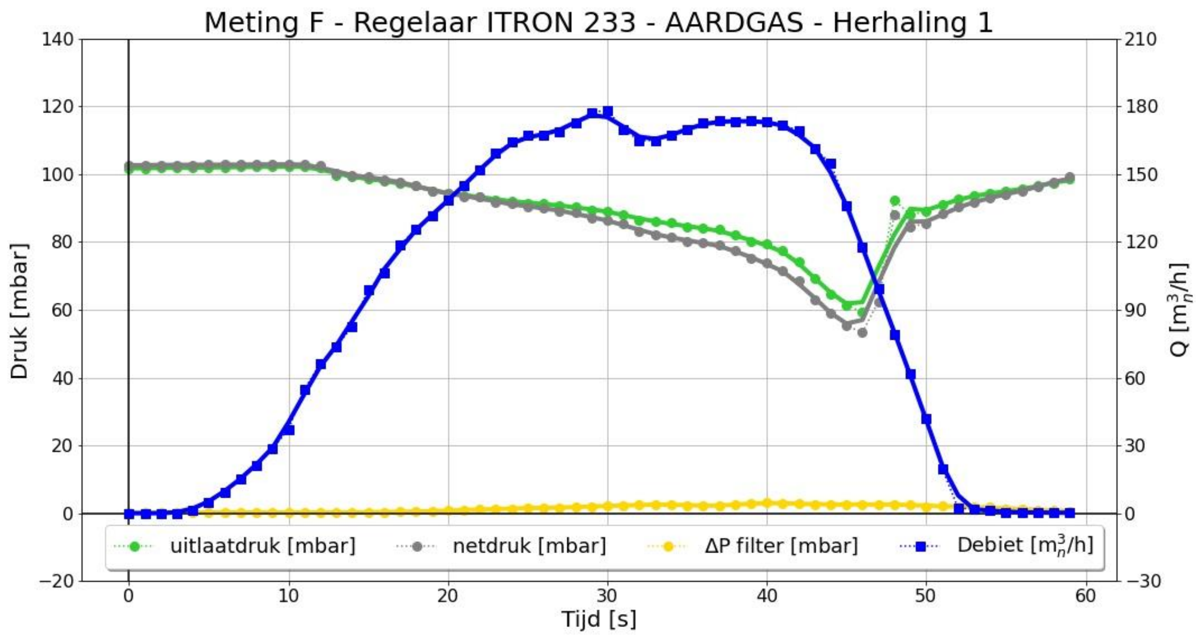
P end = 0.5 mbar

Capacity** = 8.80 $dm^3$

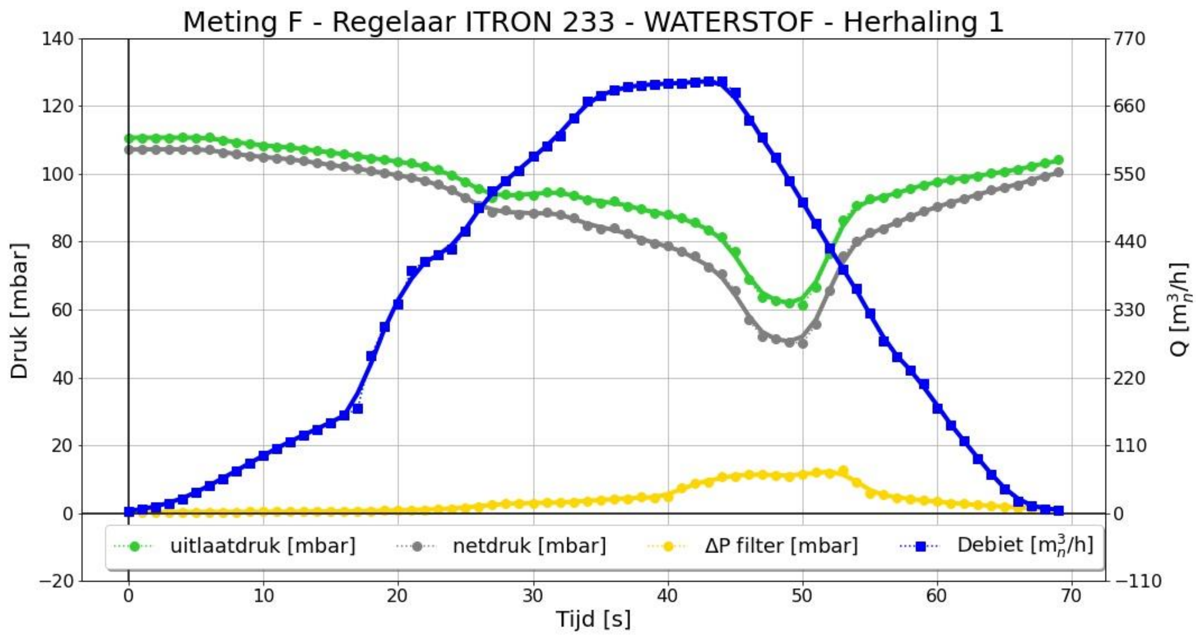
** This is the volume between the VAK and the outlet valve of the control set.

$$Internal\ leakage\ = \frac{1010{,}5 * 8{,}80}{1010{,}1} - 8{,}80 = \ 0{,}0112\ dm^3\ /\ 600\ s = 5{,}8\ mm^3/s$$

# VII Itron pressure stability graph (second measurement)

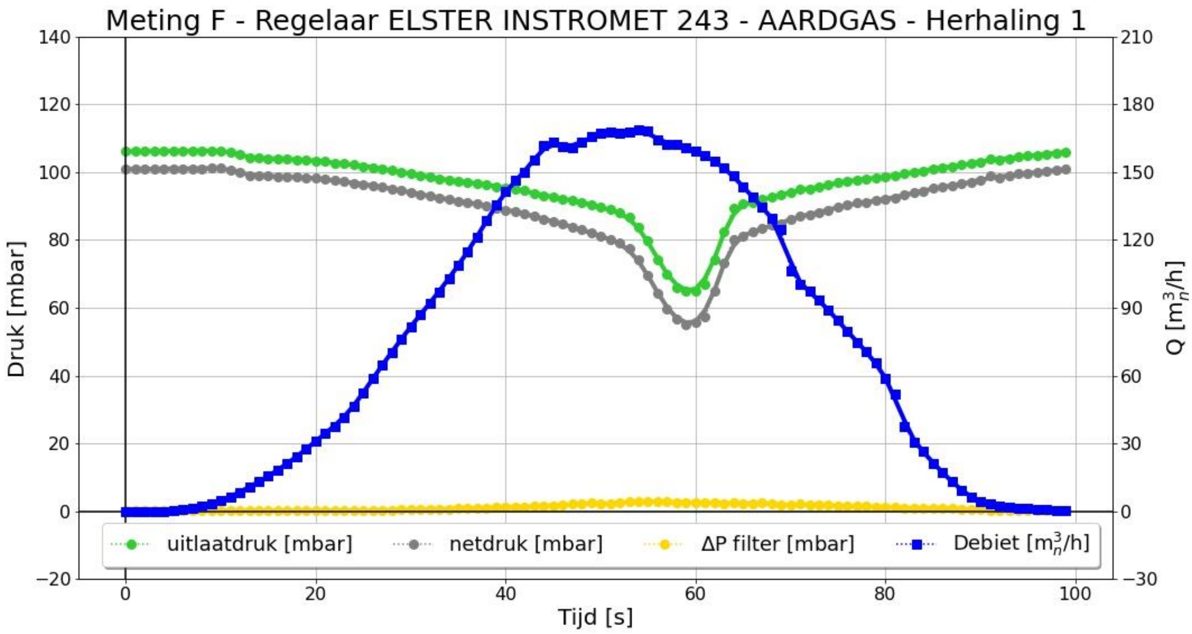



Repetition: determination of pressure stability **natural gas**

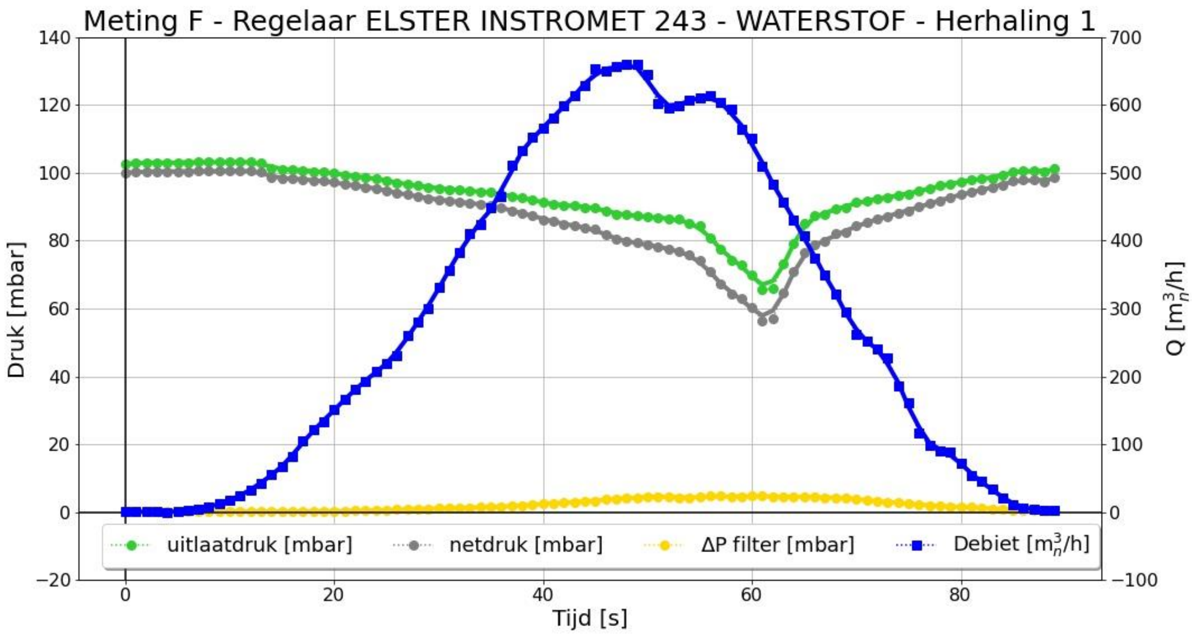



Repetition: determination of pressure stability **hydrogen**

# VIII Elster Instromet pressure stability graph (second measurement)

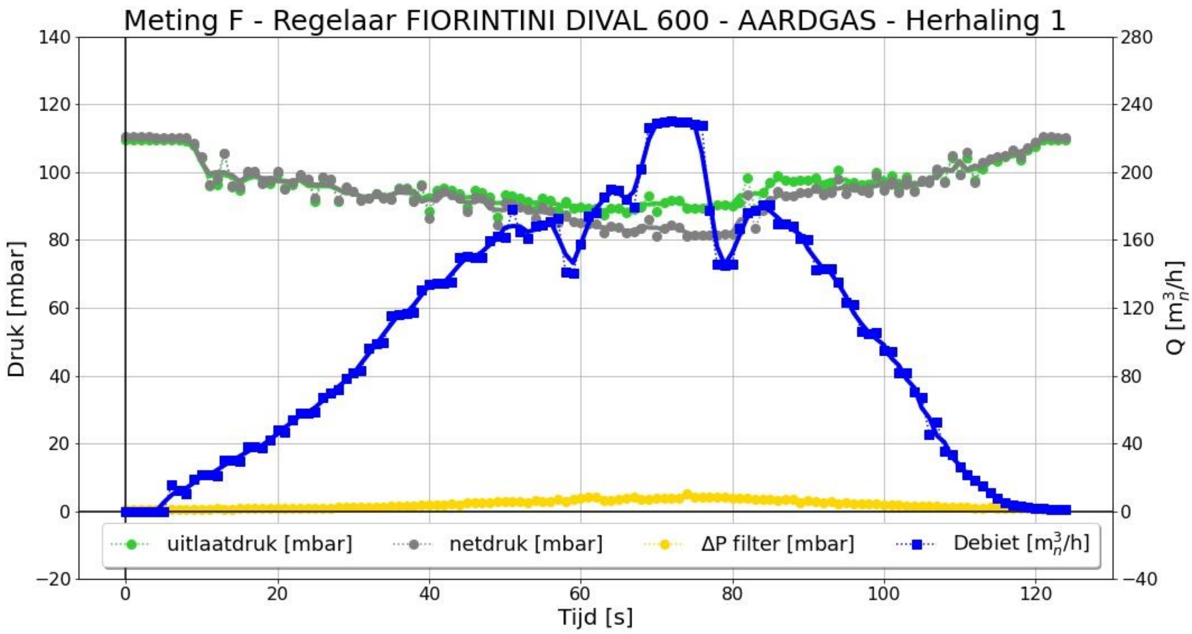



Repetition: determination of pressure stability **natural gas**

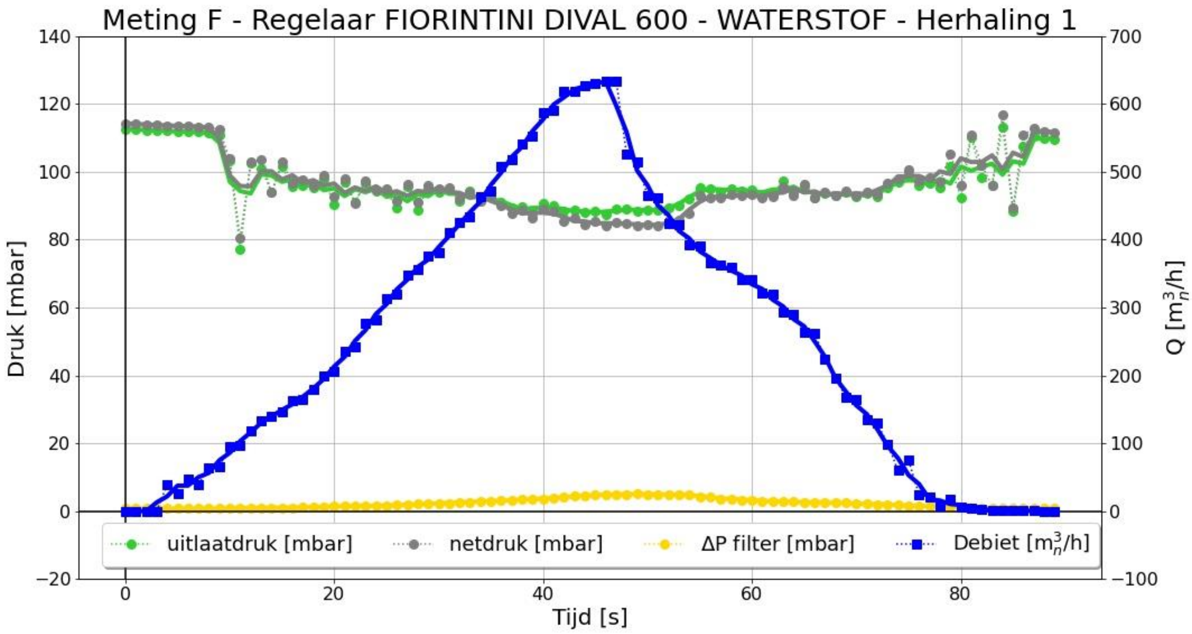



Repetition: determination of pressure stability **hydrogen**

# IX Fiorentini Dival pressure stability graph (second measurement)

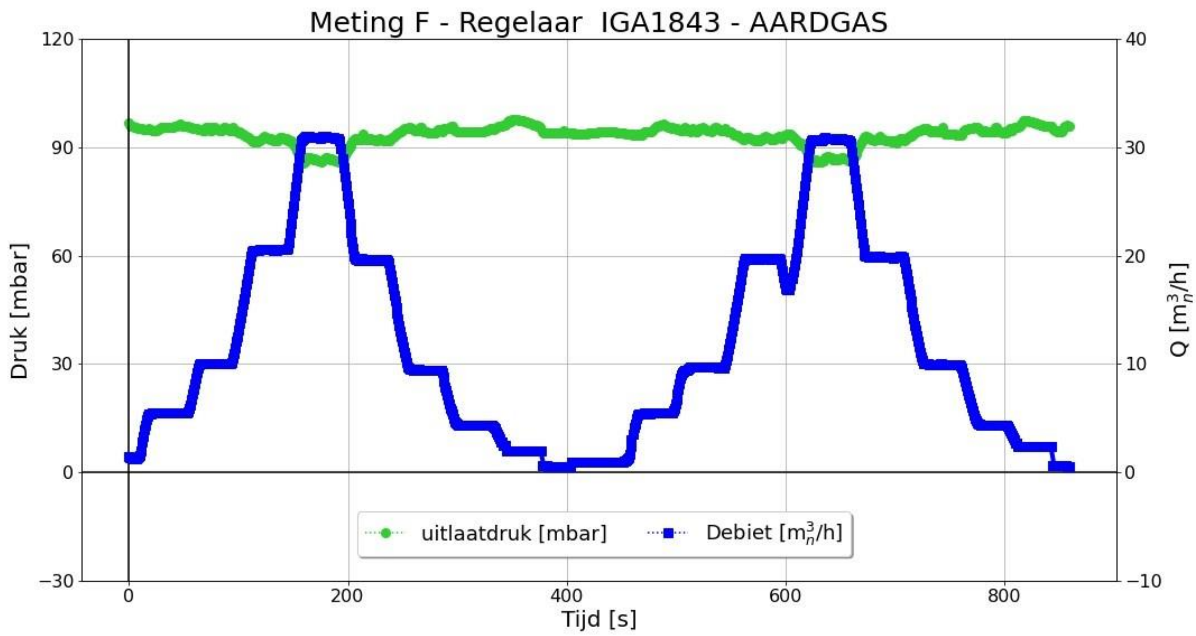



Repetition: determination of pressure stability **natural gas**

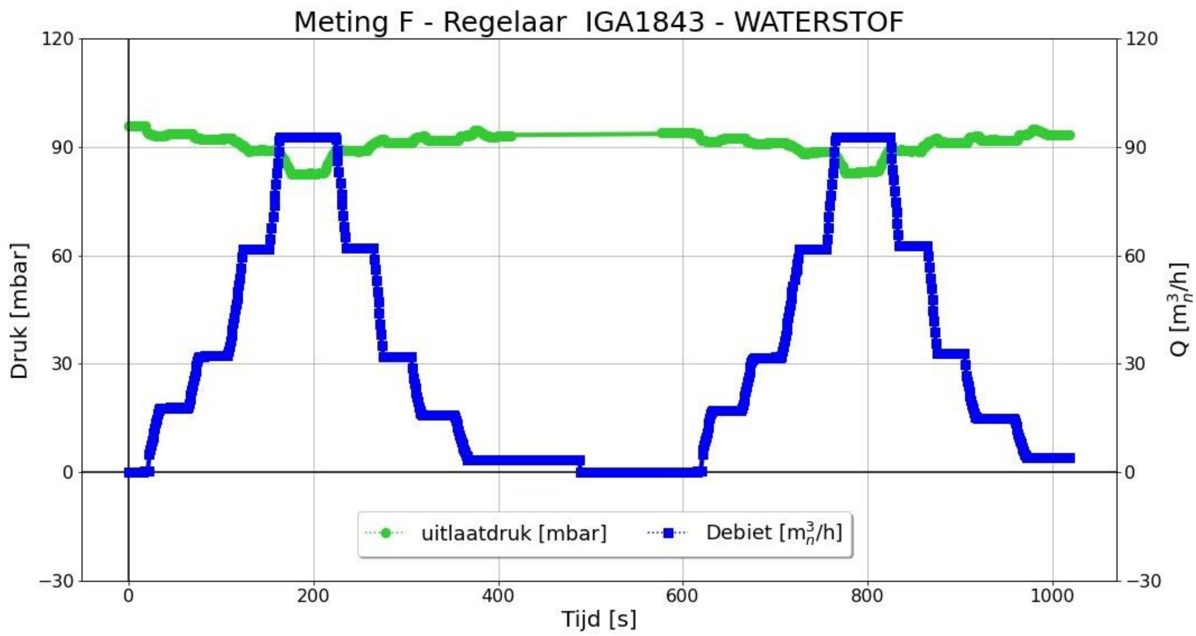



Repetition: determination of pressure stability **hydrogen**

# X IGA1843 pressure stability graph (second measurement)




Repetition: determination of pressure stability natural gas




Repetition: determination of pressure stability hydrogen

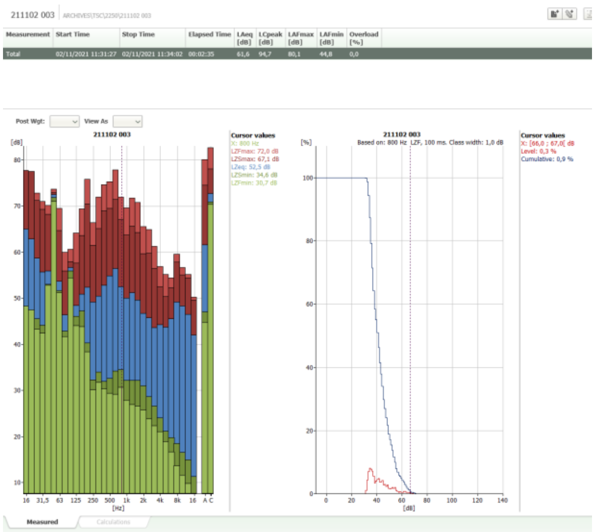
# XI Noise emissions per regulator

The noise measurements during all capacity tests were carried out with Bruel & Kjaer 2250 analyser, mounted on a tripod. This analyser can produce different cross-sections of the measured noise as shown below;

| | |
|---|---|
| LAFmax | The maximum level with a surface weighted average frequency and a fast time response. |
| LASmax | The minimum level with a surface weighted average frequency and a fast time response. |
| LAeq | The “surface weighted average equivalent” of the sound level spectrum, based on a minimum number of measurements per time unit.<br>As a result, short-lived, high measurements are not included in this average. |
| LASmax | The maximum level with a surface weighted average frequency and a slow time response. |
| LAFmin | The minimum level with a surface weighted average frequency and a slow time response. |

The data below are screenshots of the measurement data as processed by the analyser using the supplier’s software. They show both the spectrum (bar chart) and the cumulative noise spectrum (normal distribution). The surface weighted average equivalent (LAeq) was used for the comparison between **natural gas** and **hydrogen**.

Itron 233 regulator



Natural gas
LAeq = 61.6 dB

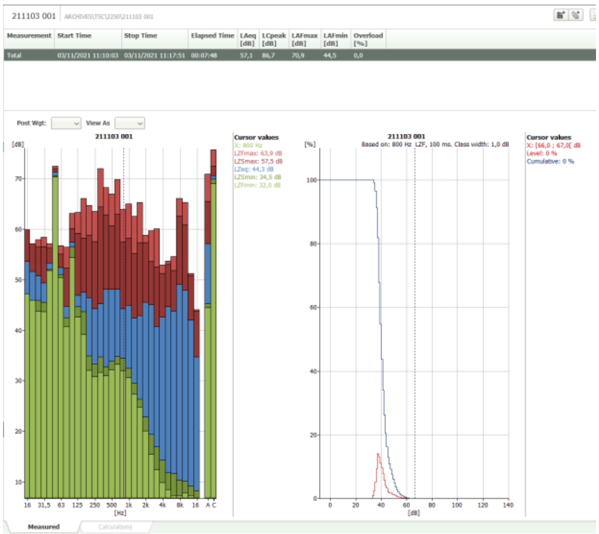
Hydrogen
LAeq = 58.4 dB

Elster Instromet regulator

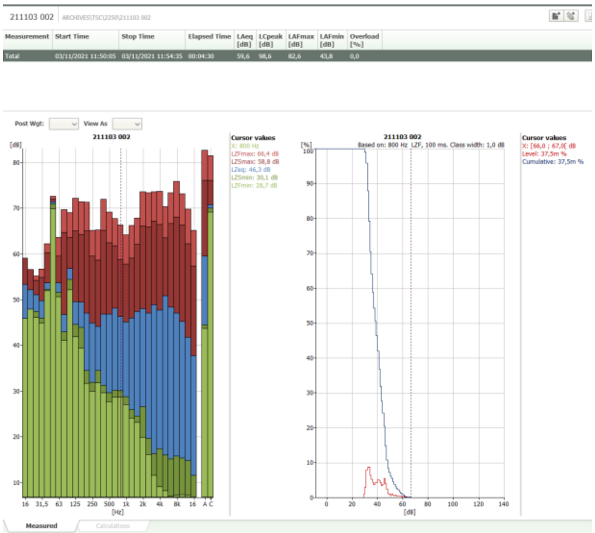
Natural gas
LAeq = 55.4 dB

Hydrogen
LAeq = 56.7 dB

Fiorentini Dival 600 regulator

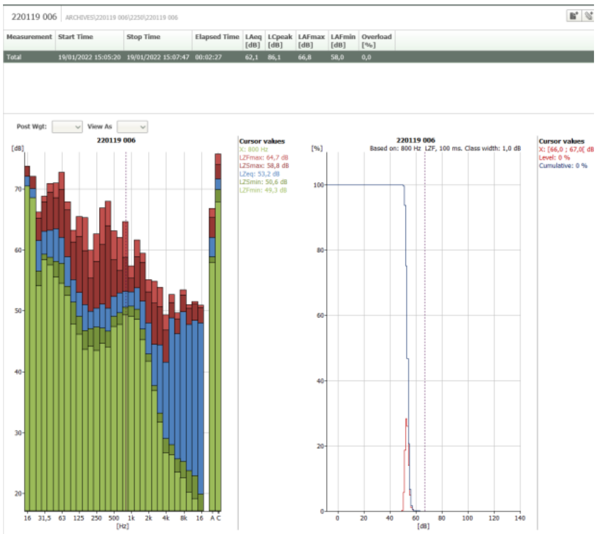


Natural gas
LAeq = 57.1 dB



Hydrogen
LAeq = 59.6 dB

IGA1843 regulator



Natural gas
LAeq = 62.1 dB

Hydrogen
LAeq = 62.6 dB

# XII Measurement data per regulator

| | | Ma, 1 nov | | Di, 2 nov | | Wo, 3 nov | | Vr, 5 nov | |
|---|---|---|---|---|---|---|---|---|---|
| **Meetnummer 1** [A] | | | | | | | | | |
| Dichtheid VA (optie 1) | | Optie 1, itron | | Optie 2, elster | | Optie 3, dival | | Optie 4, IGA1843 | |
| Dichtheid VAK (optie 4) | | CH4 | H2 | CH4 | H2 | CH4 | H2 | CH4 | H2 |
| | t (min) | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] |
| | 0 | 87,7 | 86,6 | x | x | x | x | 103,1 | 108,5 |
| | 15 | 85,3 | 84,5 | x | x | x | x | 103,3 | 107,2 |
| Delta P | (mbar) | 2,4 | 2,1 | x | x | x | x | 0,2 | 1,3 |
| Tijd | (min) | 15 | 15 | x | x | x | x | 15 | 15 |
| Stijging/daling [B] | | daling | daling | x | x | x | x | stijging | daling |
| Drukvariatie | (mbar/min) | 0,16 | 0,14 | x | x | x | x | 0,01 | 0,09 |
| Inhoud | ($dm^3$) | 15,53 | 15,53 | x | x | x | x | 0,5 | 0,5 |
| Lekkage | ($mm^3/s$) | 37,8 | 33,1 | x | x | x | x | 0,1 | 0,6 |
| Waarde voldoet aan lekrate C | ja/nee | ja | ja | x | x | x | x | ja | ja |
| | | | | | | | | | |
| **Meetnummer 2/4** | | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] |
| Reactie VA | | 180 | 182 | x | x | x | x | 163 | 164 |
| | | 180 | 181 | x | x | x | x | 162 | 162 |
| | | 180 | 180 | x | x | x | x | 161 | 160 |
| | | | | | | | | | |
| | | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] |
| Reactie VAK | | 179 | 179 | 195 | 195 | 182 | 180 | 200 | 199 |
| | | 179 | 179 | 194 | 194 | 181 | 180 | 195 | 197 |
| | | 181 | 177 | 196 | 193 | 181 | 179 | 195 | 201 |
| | | | | | | | | | |
| **Meetnummer 3/ 5** [A] | t (min) | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] | [mbar] |
| Dichtheid VAKAAN (opties 1, 2 en 3) | 0 | 87,7 | 0,1 | 4,9 | 2,3 | 84,5 | 89,4 | -1,3 | 0 |
| Dichtheid VAKAAN (optie 4) | 15 | 84,6 | 0,5 | 7,3 | 3,3 | 81,0 | 82,7 | -1,3 | 0,2 |
| Delta P | (mbar) | 3,1 | 0,4 | 2,4 | 1,0 | 3,5 | 6,7 | 0 | 0,2 |
| Tijd | (min) | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Stijging/daling [B] | | daling | stijging | stijging | stijging | daling | daling | geen | stijging |
| Drukvariatie | (mbar/min) | 0,21 | 0,03 | 0,16 | 0,07 | 0,23 | 0,45 | 0,00 | 0,01 |
| Inhoud | ($dm^3$) | 8,80 | 8,80 | 8,80 | 8,80 | 8,80 | 8,80 | 0,5 | 0,5 |
| Lekkage | ($mm^3/s$) | 27,7 | 5,8 | 23,1 | 9,6 | 31,4 | 60,0 | 0,0 | 0,1 |
| Waarde voldoet aan lekrate C | ja/nee | ja | ja | ja | ja | ja [C] | ja [C] | ja | ja |
| | | | | | | | | | |
| **Meetnummer 6** | (mbar) | 108,0 | 108,8 | 105,3 | 102,5 | 117,0 | 107,0 | 100,2 | 99,1 |
| Sluitdruk | | @ 32m3/hr | @ 90m3/hr | @ 27m3/hr | @ 86m3/hr | @ 30m3/hr | @ 95m3/hr | @ 2,7m3/hr | @ 4,8m3/hr |
| | (mbar) | 108,0 | 108,2 | 105,4 | 102,1 | 121,0 | 106,0 | 100,4 | 99,1 |
| | | @ 32m3/hr | @ 90m3/hr | @ 30m3/hr | @ 98m3/hr | @ 35m3/hr | @ 96m3/hr | @ 2,7m3/hr | @ 4,8m3/hr |
| | | | | | | | | | |
| **Meetnummer 7/8** | | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek |
| Capaciteit en regelgedrag | | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek | zie grafiek |

**A**

Toelichting testen dichtheid bij opties 1, 2 en 3

Uitsluiten van uitwendige lekkages door afzepen instalatie na inbouw regelaar.
Vastgesteld dat handbediende afsluiter op de uitlaat van het gasstation dicht is.
Vastgesteld dat handbediende afsluiter op de uitlaat van het buffer dicht is.
Dichtheid VA door VA te sluiten (voordruk 3 bar) , VAK open te laten en handbediende afsluiter tussen VAK en buffervat te sluiten.
Dichtheid VAK/AAN gemeten door VA open te laten (3 bar) - VAK te sluiten en handbediende afsluiter tussen VAK en buffervat te sluiten.
De dichtheid van VA blijft voor iedere regelaar hetzelfde.

Toelichting testen dichtheid bij optie 4

Uitsluiten van uitwendige lekkages door afzepen instalatie.
Vastgesteld dat handbediende afsluiter op uitlaat HAS volledig afdicht.
Druk voor VAK is 3 bar, druk tussen VAK en VAKAAN is ongeveer 100 mbar, druk in buffervat is 0 mbar.

Drukdalingen of drukstijgingen van 1 tot 2 mbar in de meettijd van 15 minuten zijn mogelijk een gevolg van temperatuurvariatie.
Een tiende graad Celcius wijziging van gastemperatuur zorgt voor een verschil in druk van 0,4 mbar.

**B**

Daar waar sprake is van een drukstijging zal deze het gevolg zijn van een inwendige lekkage en/of een temperatuurstijging.
Er is immers vastgesteld dat er geen sprake is van een uitwendig lek dat zichtbaar is te maken met lekzoekspray en de handbediende afsluiters stroomafwaarts zijn lekdicht bevonden.
Daar waar sprake is van een drukdaling zal de inwendige lekkage naar verwachting in ieder geval kleiner zijn dan het genoemde debiet.

**C**

Lekrate C is < 150 $mm^3/s$ ( 3 * DN 50).
Geringe lekkage bij aansluiting meetpunt druksensor P2, deze was niet te verhelpen. De waargenomen lekkage zal grotendeels de lekkage op dit punt betreffen.