HyDelta

WP1B – Gasstations

D1B.2 – Safety during maintenance works for hydrogen gasstations

Status: final

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Document summary

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Document assessment

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Executive summary

In the context of the national research program HyDelta, research has been carried out into the necessary mitigating measures for the commissioning and decommissioning of (hydrogen) gas stations.

During the commissioning and decommissioning of gasstations, there are situations in which gas is released. There are mitigating measures for the distribution of natural gas that must prevent damage and/or injury from occurring or limit the damage and/or injury. The question is whether it is necessary in the case of hydrogen distribution to adapt or supplement the mitigating measures for natural gas distribution stations.

In the HyDelta work package 1B “Gasstations”, this concerns the following questions;

208 – Which mitigating measures (VWIs) are necessary for the commissioning and decommissioning of (hydrogen) gasstations?
209 – Can the pressure be relieved safely if a safety risk has arisen?

On the basis of discussions with the network operators, an inventory of the various situations in which gas is released has been created. The amount of hydrogen that is released was then determined by means of calculations.

Based on the calculations and previous research, the following has been concluded;
For a safe commissioning and decommissioning (including pressure relief after a safety interference) the following mitigating measures are necessary;

Use the mitigating measures described in VWIs G-51, G-52, G-53 and G-54. Use suitable hydrogen gas detection equipment and suitable anti-static clothing.

In addition to the requirements for vent/flare installations, as described in NEN 7244-7, implement the following measures:

- Use a hydrogen flame arrester when flaring and when venting.
- Make sure that there are no obstacles in the immediate vicinity of the flare or venting point.
- Maintain a distance between the outlet point and possible ignition sources of 2 to 3 greater than with natural gas. (indicative distance of 7 metres, field research is necessary to verify).

Avoid gas outflows directly on the installation, use a vent/flare installation when depressurising the gas control installation completely.

Contents

1. Introduction

This research has been carried out within the framework of the national research programme HyDelta. The programme focuses on the safe integration of hydrogen into the existing gas transport and distribution infrastructure and aims to remove barriers that hamper innovative hydrogen projects. The complete research programme is divided into work packages. One of these work packages is the Gas Stations work package (for an explanation of the different work packages see www.hydelta.nl). This work package investigates how the current gasstations can safely be used to reduce pressure of hydrogen gas in the distribution network. One of the aspects involved is carrying out work on these stations.

During the service life of a natural gas station, activities are carried out including commissioning and decommissioning of stations and equalising the pressure if one of the safety devices has been activated/or to reset the safety devices. These activities involve controlled gas outflow. If hydrogen instead of natural gas is to be distributed in the future and if the method remains unchanged, hydrogen will be released instead of natural gas. The question is whether more or different measures are needed in order to carry this out safely. The following two questions have been formulated for this purpose;
208 – Which mitigating measures (VWIs) are necessary for the commissioning and decommissioning of stations?
209 – Can the pressure be relieved safely if a safety risk has arisen?

This research is based on the mitigating measures as described for natural gas. It was then determined whether these mitigating measures are applicable in the case of hydrogen and whether they have the same effect.

The assumption is that, with an unchanged installation design, hydrogen will be released during certain specific activities at the gas station, just as with natural gas. As a result, no additional hazards arise as compared with natural gas (the danger of igniting the released hydrogen gas remains).

In this research, gasstations are understood to be high pressure delivery stations (HAS) and district stations (DS); see Annex 1 for an explanation. Delivery stations, custody transfer stations and transhipment stations fall outside the scope of this research.

2. Approach

In order to answer questions 208 and 209, it is important to have insight into the quantity and behaviour of the hydrogen that is released during the activities mentioned. The following activities were conducted in order to gain that insight:

1. Interviews with the regional grid operators were used to identify the activities that result in gas being released at natural gas high pressure delivery stations (HAS) and district stations (DS).
2. Based on the results from step 1, determine the amount of hydrogen gas that may be released during these operations.
3. Determine whether the results from step 2 would necessitate more or different mitigating measures.

3. Overview of activities

Based on interviews with the grid operators, the following activities were identified that involve the release of gas during the commissioning and decommissioning of natural gas stations (more precisely, the commissioning and decommissioning of the gas control line). A summary of the interviews is included in Annex 1.

- During commissioning, the station (DS and HAS) must be purged so that the medium present at the time is removed from the station. A new station is filled with air, whereas when converting from natural gas to hydrogen, the station is filled with natural gas. This must first be completely removed and either vented or flared. In addition, the regulator settings and the safety devices have to be checked and reset. The gas is vented through the balancing valve and, depending on the amount, is vented via a vent pipe (possibly to the outside).

- During the B-inspections (DS only, a B-inspection at a HAS is uncommon) the regulator pressure, outlet pressure and closing pressure of the active regulator and monitor (if applicable) are checked. During a number of these actions, it is necessary to create gas flow, and the balancing valve is used for this as well. The response pressures of the safety devices are also checked by increasing the pressure. When the pressure is lowered again afterwards, a small amount of gas is released through the measuring kit.

- During the replacement of parts and/or repair of a defective part (for example, the replacement of a filter or regulator) or during C-inspections. A C-Inspection is an internal inspection of components such as regulators, safety devices, filters, etc. The installation must be completely depressurised with the risk of releasing the contents of the control line or components (residual gas in the installation). In the case of a HAS, the decision is often made to replace the entire HAS.

- Pressure equalisation of the cylinder from the safety shut-off valve (VA), if present, after a procedure or during the performance of a B-inspection.

4. Defining loss of containment scenarios

In order to be able to calculate the size of the gas cloud that is created during the activities described in Chapter 3, it is necessary to determine the amount of gas that is released. For this purpose, the activities in Chapter 3 have been depicted in 5 scenarios. Based on the information obtained during discussions with the grid operators, a choice has been made for these five scenarios in terms of the balancing valve diameters, pipeline diameters and height of the venting. For scenarios 1-1 and 1-2, it is assumed that a 25-metre long supply line is used.

- HAS Scenario 1: Commissioning. Venting of the supply line in combination with the contents of the station via the balancing valve with DN 15 (½") venting at a height of 2.5 metres at a pre-pressure of maximum 8 bar, for several minutes.

- HAS Scenario 2: B-inspection "as it shouldn't be done". Vent 10 litres of gas (contents of the installation) with overpressure of 160 mbar to 100mbar directly on the DN 15 (½") balancing valve at a height of 1 metre (normally this should be vented with a hose to a tree or tripod).

- DS Scenario 1-1: Commissioning. Vent or flare the 25 metre DN80 (3") supply line with DN25 (1") vertical discharge at a height of 2.5 metres at a maximum upstream pressure of 8 bar for a few minutes.

- DS Scenario 1-2: Commissioning. Vent or flare the 25 metre DN 150 (6") supply line with DN 25 (1") vertical discharge at a height of 2.5 metres at an initial pressure of max. 1 bar for a few minutes.

- DS Scenario 2: B-inspection. Vent 10 litres (contents of the installation) at the DN 25 (1") balancing valve at a height of 1 metre at a maximum pre-pressure of 160 mbar.

The following activities were not analysed further;

- Replacement of parts or internal inspections, such as during the C-inspections. This activity is carried out in a depressurised (not gas-free) environment. The amount of gas released in this process is minimal and brief. Determining an outflow that would lead to a danger zone is not worthwhile for this activity.

- Pressure equalisation when resetting a safety device. This activity is also carried out during a B-inspection (see Scenario 2) and is therefore not analysed separately.

Determining the extent of the gas outflow

In order to gain insight into the extent and distribution of the gas released in the scenarios described, the Antea Group[1)] was asked to carry out simulations. Using the software (PHAST 8.4), the dispersion of the released hydrogen was defined. The findings of the report [1] are summarised below.

When carrying out the simulations, Antea Group found that the volumes released in a number of scenarios were below the minimum quantity that can be performed with the simulation software. This means that the figures and distances included in the Antea report are not representative of the actual situation occurring during the described activities at gas stations. The simulations carried out do show the difference in behaviour of the outflow between natural gas and hydrogen. For this reason, the decision was made to incorporate the findings but not the figures in order to avoid giving a misleading impression of the release of hydrogen gas.

Findings from the Antea Group report

When comparing flaring scenarios with the same outflow conditions for hydrogen and natural gas, it can be seen that hydrogen forms significantly larger and further reaching ignitable clouds (distances 2 to 3 times as far).

Flaring the same hydrogen outflows produces significantly smaller heat radiation contours than for natural gas (distances 20 to 30% smaller).

The outflow speed of the hydrogen gas is relatively low at a few tens of metres per second (non-choked flow), which means that there is limited turbulence intensity in the discharge. This is an important fact for emissions with hydrogen because of the considerably higher burning rate as compared to natural gas and the considerably greater potential for flame acceleration. [Kiwa comment; the low outflow velocity and thus the limited turbulence is a positive effect as this limits the chance of flame acceleration]

For hydrogen ejections in the open air, the pressure build-up of an (incidental) delayed ignition resulting in a jet explosion is low because of the low turbulence intensity. A potential explosion overpressure in the cloud of maximum 3 kPa must be taken into account. This overpressure poses no threat to personnel or nearby windows. **However, it is recommended not to discharge the vent pipe into the crown of a tree, as this obstacle configuration can lead to high turbulence with increased flame acceleration and additional pressure build-up.**

For the very brief outflow from the HAS cabinets, the potential heat radiation from the flame is very short, which means that the heat radiation dose will be zero. The danger lies in the flame contact. If the flammable cloud burns, the expanding combustion products will cause the cloud to expand. The volume will increase by a maximum factor of 8 (an average doubling of the cloud's dimensions). This is illustrated in Figure 1 below.

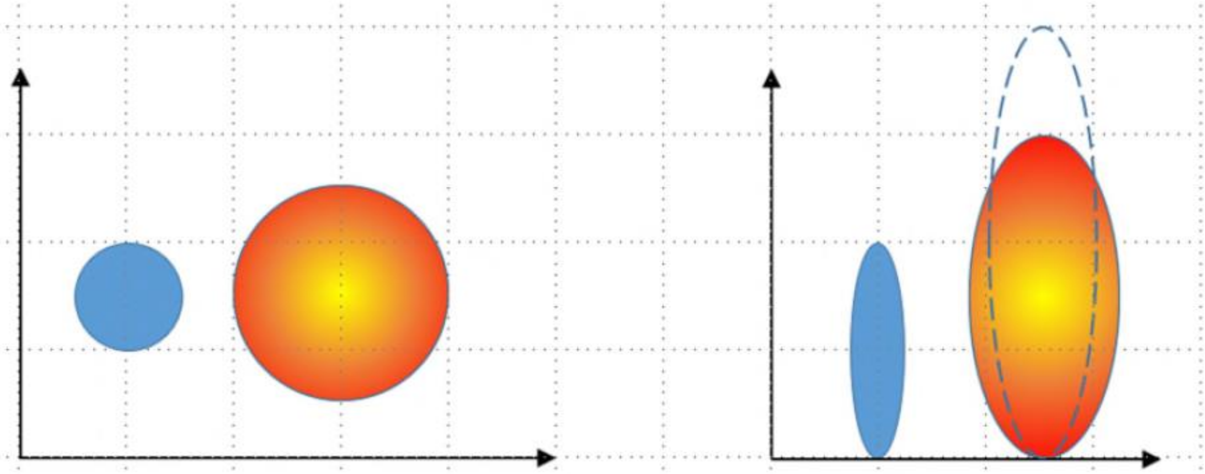

Figure 1. Enlargement of an expanding flammable spherical cloud (left) and ellipsoidal cloud (right)

For an ellipsoid with a length to width ratio > 4:1, the main expansion will be lateral (the ellipsoid becomes slightly longer and significantly thicker). For a narrow ellipsoid of up to 1 metre in length, the cloud expansion will not extend the flame beyond 50%. The expansion in width will not exceed 300% (the expansion factor 8 “worst case” distributed over two degrees of freedom → √8 = 2.8).

It appears that maintenance operations with hydrogen in the natural gas pipeline network may produce larger combustible clouds with larger incidental (delayed) ignition probabilities. However, the effect of ignitions in the open air does not result in additional hazards from pressure build-up. The heat radiation around flare lines is significantly lower for hydrogen discharges. **If no flaring installation is used, increased safety distances for heat radiation effects associated with occasional delayed ignitions should be taken into account.**

Based on these results, it is advisable to avoid gas flares directly on the installation without a vent hose.

[1] Antea Group is a Dutch consulting and engineering firm that operates internationally in the fields of hydraulic engineering, infrastructure, coastal engineering, real estate, urban development, environment, safety and project management.

5. Mitigating measures

During the work on natural gas reducer stations, natural gas is either flared or vented. When venting natural gas, it is possible for an ignitable gas/air mixture to form that can cause damage and/or injury. The measures described in the VWIs and VIAG are aimed at preventing the release of natural gas from ultimately resulting in damage and/or injury.

When performing work on gas stations (natural gas), the safe working instructions (VWIs) G-51, G-52, G-53 and G-54 (see references) apply.
The VWIs prescribe the following regulations regarding the danger of natural gas release;

- Ventilate the workplace.
- Leave the work area at >10% LEL.

The VWIs also describe personal protective and safety equipment.
Protective equipment:

- Anti-static and flame retardant work clothing.
- Hearing protection.
- With roadside work: reflective clothing.

Safety equipment:

- Gas signalling devices with acoustic and optical signal.
- Gas concentration meter 100% natural gas.
- Fire extinguisher.
- Fire blankets.

For the general risks and measures, the VWIs refer to Chapter 4.4. of the VIAG.
For venting or flaring the natural gas released during operations, no specific mitigating measures are described in the VWIs or VIAG.

The measures described in the VWIs represent a range of safeguards intended to prevent damage and/or injury or to limit damage and/or injury.

Figure 2 below gives an overview of the sequence of the release of natural gas leading to damage and/or injury and the various mitigating measures (safeguards) intended to prevent this.

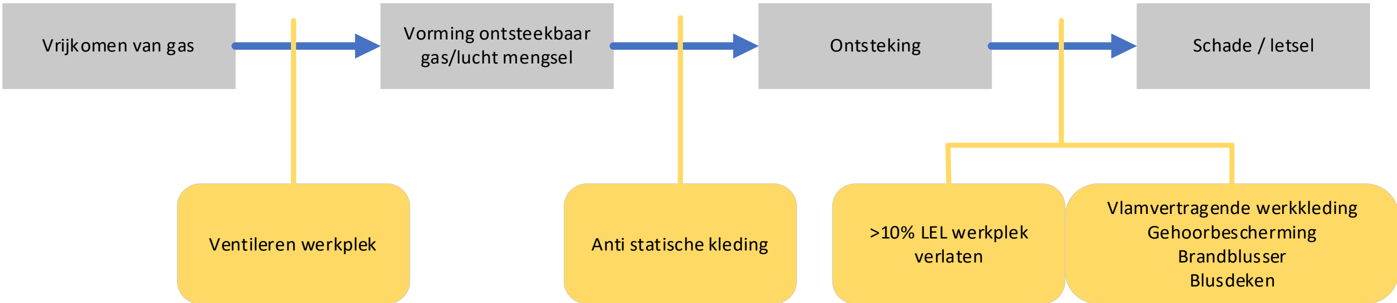

Figure 2. Schematic overview of mitigating measures

6. Assessment of the mitigating measures from the VWIs

In this chapter, the suitability and effectiveness of each mitigating measure (as described in Chapter 5) for activities at hydrogen gas stations has been assessed (expert opinion).

Measure: Ventilate the workplace
Ventilating the workplace is also a suitable basic measure for hydrogen with the aim of diluting and ventilating released hydrogen gas. The effects of ventilation (as with natural gas) depend on the prevailing wind direction, wind speeds and the potential for air exchange in the gas station (e.g. an indoor gas station).

Measure: Anti-static clothing
Research into the suitability (and thus the effectiveness as a measure) of anti-static clothing in the case of hydrogen is being carried out within the Knowledge Centre of the gas network operators. At the time of writing this report, the research had not yet been finalised.

Measure: Leave the work area at >10% LEL
When hydrogen is concerned, the area where the gas concentration in air is less than 10% of the LEL value (10% LEL = 0.4% hydrogen in air) is a safe area. For hydrogen, this continues to be an appropriate and effective measure as there is no risk of ignition of the hydrogen gas/air mixture.

Suitable detection equipment is required in order to detect the 10% LEL. The suitability of detection equipment is investigated in Kiwa report GT-200046 'Suitability of gas measurement equipment for hydrogen' May 2021.

Measure: Flame retardant work clothing/hearing protection/fire extinguisher/fire blanket
With regard to these measures, there is no reason to use other means in the case of hydrogen as the consequences are the same as for natural gas. These measures continue to be effective in limiting damage and/or injury.

7. Mitigating measures for venting and flaring

The Antea report and the Kiwa report GT-200096 'Flaring and venting hydrogen' [2] have been used to compile the relevant findings in terms of mitigating measures in the event of flaring gas and venting hydrogen gas.

Report GT-200096 describes the research into safe and effective venting and flaring of hydrogen pipes.

Measures for venting hydrogen gas

- If venting is not carried out via a flaring installation, then it is necessary to take into account the increased safety distances for heat radiation effects associated with incidental delayed ignitions.
- The distance between the outflow point and potential ignition sources used for natural gas must be increased by a factor of 2 to 3 for hydrogen.
- It is advisable not to allow the vent pipe to end in the crown of a tree, as this obstacle configuration can lead to high turbulence with increased flame acceleration and additional pressure build-up.
- Use a vent pipe made of stainless steel or a non-sparking metal (this measure comes from the report 'Flaring and venting hydrogen' and is taken from EIGA document 121/14 [11]. As a focus point when venting hydrogen, the EIGA document mentions the following; 'to minimize the possibility of auto ignition when hydrogen leaves the stack, it is recommended that the piping immediately upstream of the exit be made of stainless steel or a non-sparking metallic material')
- The outlet of the vent must be at least 2.5 metres above ground level.
- Potential equalisation (grounding of the venting installation) must be provided.

Measures for flaring hydrogen gas

- A hydrogen flame arrestor must be used when flaring.
- When flaring hydrogen, a smaller safety distance with regard to heat load will suffice (20-30% less compared to natural gas).
- The outlet of the flare must be at least 2.5 metres above ground level.

Compare with the NEN 7244-7 [10]

Chapter 5.1 of NEN 7244-7; 2019 describes the requirements that a flaring and/or venting installation must comply with for the flaring and/or venting of pipes. This concerns the following points:

- Made of metal.
- Of a sufficient capacity.
- Provided with a shut-off valve with full passage and a sampling point.
- Provided with an automatic ignition mechanism for a flaring installation.
- Prevention of uncontrolled discharge of static electricity.
- Stable setup.
- Positioned vertically in the open air, with the outlet at least 2.5 metres above ground level.
- Installation at a safe distance from possible ignition sources and buildings.

If the venting point is inside a building, venting is allowed via a flexible hose, the end of which must be placed outside the building. The following additional safety measures must be taken:

- Flame arrestor at the end, or a metal end.
- Static electricity must be prevented (e.g. by an anti-static hose).
- The hose end must be fitted with a shut-off valve.
- Tighten the hose to prevent uncontrolled movements.
- Select the location of the end so that the gas to be discharged cannot enter the building, e.g. by taking the wind direction into account.

When comparing the current requirements for flaring/venting natural gas (NEN 7244-7) with the results of this research, we have found that for flaring/ venting hydrogen gas, compared to NEN 7244-7, the following additional measures should be taken:

- Use a flame arrestor for both flaring and venting.
- Make sure that there are no obstacles in the immediate vicinity of the outflow point.
- Maintain a distance between the outflow point and possible ignition sources of 2 to 3 greater than with natural gas.

Note. NEN 7244-7 Chapter 5.1 describes: “Position at a safe distance from possible ignition sources and buildings”; a distance is not specified here. Based on the calculations from the Antea report, an indicative distance when venting hydrogen is 7 metres surrounding the outflow point. It is recommended to check this distance through practical testing and to include it in the instructions/work regulations.

8. Conclusion

The following mitigating measures are necessary for safely commissioning and decommissioning gas stations (including pressure equalisation after a safety procedure);

Use the mitigating measures described in VWIs G-51, G-52, G-53 and G-54. Use suitable hydrogen gas detection equipment and suitable anti-static clothing.

In addition to the requirements for vent/flare installations, as described in NEN 7244-7, implement the following measures:

- Use a hydrogen flame arrester when flaring and when venting.
- Make sure that there are no obstacles in the immediate vicinity of the outflow point of the flaring or venting.
- Maintain a distance between the outflow point and possible ignition sources of 2 to 3 greater than with natural gas. (indicative distance of 7 metres, field research is necessary for verification).

Avoid gas leaks directly on the installation. Use a venting/flaring installation when the gas control installation is completely depressurised.

HAS cabinets

HAS cabinets are high pressure delivery stations. In a HAS, the pressure is reduced from high pressure (1, 4 or 8 bar) to low pressure (100 mbar). The capacity is typically up to 40 m^3_n/h.
A HAS usually has two places where a vent can be connected. There is a T-piece with a DN 8 (¼”) valve on the inlet side. There is also a T-piece with a DN 8 (¼”) or DN 15 (½”) valve on the outlet side (after the pressure regulator).

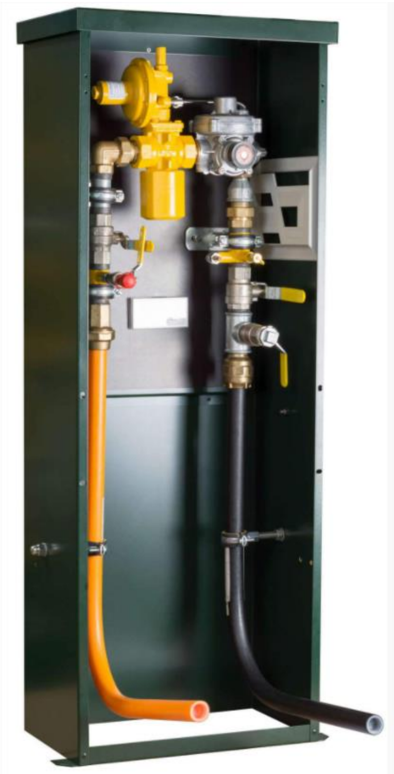

Figure 1. Example of a HAS

Commissioning

When commissioning the HAS, both the pipe to the HAS and the pipe in the HAS cabinet must be vented.

Which point is used to connect the vent depends on the specific situation. You may choose to use the DN 8 (¼”) connection after the pressure regulator to vent both the pipe section and the HAS, which is the balancing valve. An anti-static hose then needs to be mounted on this connection. This hose is often mounted on a tree or a fence. An alternative is to use a vent pipe at a height of 2.5 metres. The choice varies from network operator to network operator.
Another method is to use sectioned venting. In this case, the high pressure line is vented first. The DN 8 (¼”) connection at the entry of the HAS is used. This is connected to the previously mentioned 2.5 metre vent. Afterwards, the HAS itself is vented via the balancing valve. This is a small amount. It depends on the situation and the grid operator whether the ‘vent’ is used for this or the hose.

B-inspections on HAS

A B-inspection checks whether the pressure safety device engages at the correct pressure. Performing B-inspections on HAS is not common practice for most grid operators. If this is done, the following procedure applies:

- The cabinet is opened, the area is closed off and an ‘open fire prohibited’ sign is posted.
- Exhaust valve is closed
- The pressure is increased by opening the regulator
- When the pressure increases, the VAK closes.
- The overpressure in the system is vented by unscrewing the cap of the VAK. A minimal amount of gas is released.
- The regulator is turned back to its initial value,
- The outlet valve is opened again.

This is a situation in which a small quantity of gas is released at the height of the VAK, i.e. not at 2.5 metres, but at the height of the VAK (approx. 1 m above ground level).

C-inspections and large-scale maintenance

The grid operators deal with replacement of and at HAS cabinets in different ways. The most common approach is to replace the entire HAS cabinet if it encounters a problem. A spare HAS is connected and the following actions are carried out:

- On the inlet side of the HAS, the inlet valve is closed.
- The spare set is vented. This is done on the ground where the set is temporarily placed.
- The existing set is depressurised.
- The existing set is disconnected.
- The spare HAS is connected. The set is vented in accordance with the procedure described in 2.1.

District stations

District stations reduce the pressure of the preceding high pressure network (8 bar, 4 bar or 1 bar) to the low pressure network (100mbar or 30 mbar). The capacity is greater than 40 $m^3{}_n$/h.
In practice, free-standing stations (capacity ≥15 m^3), cabinet stations (capacity between 0.5 m^3 and 15 m^3) and cabinets (capacity ≤0.5 m^3) are the most common.

A DS usually has two places where a vent can be connected. There is a T-piece on the inlet side with a DN 20 (¾”) tap (this is often the vent valve on the filter). There is also a T-piece on the outlet side (after the pressure regulator) with a DN 20 (¾”) tap and/or a DN 25 (1”) tap, which is the balancing valve.

Figure 2 An example of a 1/2 m3 folding cabinet

Commissioning

With a district station, the pipeline to the station and the contents of the station must also need to be vented before commissioning. This can be done in two ways:

- Using the balancing valve, which is located in the low pressure part of the station. A hose is connected to this valve (DN 20 or DN 25) to a vent at a height of 2.5 metres
- Flaring on the pipeline itself. The contents of the station must then be vented or flared separately.

B-inspections

B-inspections check whether the safety equipment of the station is activated at the correct response pressure. To check this, the station outlet valve is closed and the pressure between the pressure regulator and the outlet valve is increased. After checking, the excess pressure that has been deliberately created must be discharged.
A large number of the grid operators use the Plexor measuring kit for the B-inspection. With this measuring kit, the pressure is increased using the measuring kit, which has a connection to the inlet and outlet side of the station and also using a protected switching valve on the sensing line of the safety devices. With this measuring kit, all gas flow takes place via the measuring kit and the outgoing hose. This outgoing hose is hung on a tree or another object at a height. The amount of gas released is limited (approximately 20 litres).

Some grid operators do not use the measuring kit. In that case, the safety devices are checked by increasing the pressure (after closing the outlet valve) by turning in the regulator. When the safety has been activated, the pressure regulator is turned back to its initial position. The overpressure is discharged through the balancing valve. The balancing valve should be connected with a hose to a height of 2.5 metres. However, due to the very small amount of gas, in practice it is sometimes (not usually) vented directly to the balancing valve.

C-inspections and large-scale maintenance

When a substation requires major maintenance (e.g. when the filter housing needs to be 'pulled', or when the soft parts of a regulator need to be replaced), the following procedure is applied:

- A check is carried out to determine whether there is sufficient capacity in the network to guarantee the supply without this station.
- The inlet and outlet valves of the control line are closed.
- On the balancing valve, a flexible hose is connected to a 2.5-metre vent. The balancing valve is opened. The district station is depressurised. At that moment, the station is still filled with natural gas, at atmospheric pressure.
- When the station is depressurised, the necessary actions are carried out, e.g. the components are removed. Gas is released when a filter is removed.

Annex 2 – Overview of the guidance and sparring group

Table 1 – Members of the guidance group and sparring group

Name	Affiliation	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.			

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