Switching from a natural gas distribution grid to a 100% hydrogen distribution grid

Practical testing with hydrogen

S.L.M. Lueb
Kiwa Technology, Apeldoorn, The Netherlands, e-mail: sander.lueb@kiwa.com

S.T.M. Delnooz
Kiwa Technology, Apeldoorn, The Netherlands, e-mail: sjoerd.delnooz@kiwa.com

Abstract

Gas distribution grid operators in the Netherlands prepare for a carbon neutral future, where part of the natural gas distribution will be replaced with 100% hydrogen. Feasibility studies, experiments and pilot projects are being carried out to gain a broader understanding of how hydrogen can be used in practice. The HyDelta[1] national research programme was launched to coordinate the various studies in the Netherlands.

This article presents a summary of the results and insights gained concerning the following topics from the research projects:

- Leak tightness of the existing distribution grid
- Purging of new and existing pipelines
- Sectioning in the event of planned works or incidents

The studies were primarily necessitated by the differences between the properties of hydrogen and natural gas. These differences have several consequences:

- In the event of a leak, the leakage rate is greater for hydrogen
- The wider flammability limits for hydrogen increase the risk of ignition
- The ignition energy required for hydrogen is lower in an ideal mix of gas and air
- The impact of an explosive ignition is greater for hydrogen

In light of these differences, it is necessary to assess the suitability of existing assets and working procedures. This article does not describe the assessment of the suitability of the asset pipe materials for use with hydrogen. This must however be determined before these materials can be used with hydrogen in practice. [1]

The studies showed that the natural gas distribution grids can be converted for use with hydrogen, provided that appropriate measures are taken. Activities such as purging, temporarily shutting off, venting and flaring can be carried out safely with hydrogen, although extra measures may be required.

[1] *HyDelta is a Dutch national research programme that aims to remove barriers that currently impede the large-scale use of hydrogen in the Netherlands, and in particular the safe integration of hydrogen into the existing gas transport and distribution infrastructure. The research results are publicly available, so that society as a whole can benefit from the results of this research programme. See www.hydelta.nl for more details and reports.*

Keywords
Hydrogen, natural gas, leak tightness, purging, flaring, venting, sectioning, squeezing, inflatable gas stoppers, excess flow valves, entrance of air, nitrogen.

Leaks
Distribution grids must be gas tight. This applies to natural gas and of course also to hydrogen. If a grid is gas tight when used with natural gas, it will also be gas tight when used with hydrogen. However, the leakage rate of hydrogen is greater, which has practical consequences. A study was carried out [2] to develop recommendations for the leak tightness standards for main lines and service lines in the Dutch situation.

Leakage rate of hydrogen 1.3 to 3 times greater than natural gas
The difference between the leakage rates of hydrogen and natural gas can be determined using the differences in gas properties. For a turbulent flow, the difference in density is the determining factor. For a laminar flow, the difference in viscosity is primarily responsible for the difference in leakage rate. The emergence of a turbulent or laminar flow in the distribution grid depends on the situation, including the gas pressure and leak opening type. With a turbulent flow, the leakage rate of hydrogen is up to 3 times more than that of natural gas. For a purely laminar flow, the leakage rate of hydrogen is 1.3 times greater than that of natural gas. As these theoretical bandwidths are rather wide, experiments have been performed as part of HyDelta [2] to determine the leakage rates of natural gas and hydrogen for an identical leak opening.

Leaks in service lines have a higher hydrogen leakage rate and thus an elevated risk
As leaks in service lines can lead to the accumulation of gas in buildings, these leaks are more hazardous compared to leakages in main lines. In the study, four different leaks were created in service lines. The difference between the leakage rates of hydrogen and natural gas was then measured at various gas pressures, namely 30, 100 and 200 mbar. As expected, increasing the pressure led to a higher leakage rate for both natural gas and hydrogen. After multiple measurements were carried out, it was determined that an average of 1.8 times as much hydrogen will flow out of the same leak opening as natural gas.

It is recommended that a stricter leak tightness standard for existing service lines should apply for hydrogen. In addition to the increased leakage rate, this is due to the differences in flammability and flow behaviour. The leak tightness standard should be a factor of 1.35 stricter compared to the standard for natural gas. This is applicable when testing on tightness by using air or nitrogen and using the pressure drop method. See [2] for a detailed explanation. When switching to hydrogen, it is recommended that the leak tightness of all service lines should be assessed by carrying out a pressure drop test.
For new service lines the tightness criteria for hydrogen are equal to the criteria of natural gas, while this value is practically 0 dm^3/h.

An Excess Flow Valve is sometimes installed at the junction between main lines and service lines in the Netherlands to reduce the hazards associated with major gas leaks in service lines resulting from damage due to excavation works etc. This measure is also recommended when hydrogen is used. Research into the use of EFVs with hydrogen [3] has shown that current Excess Flow Valves also function correctly with hydrogen: the flow rate at which the valve shuts off is around three times greater than the flow rate for natural gas.

Leakage of hydrogen in main lines results in greater leakage loss but does not result in an elevated risk

Despite the increased leakage rate, which may be up to three times greater, no stricter leak tightness standards are required, as there is little risk that leaks in main lines will result in the accumulation of gas in buildings. However, it is recommended that the leak tightness of the existing distribution grid should be tested before switching to hydrogen to provide insight into unexpected leaks. This may be done by searching for leaks above ground if the grid is still being used to distribute natural gas. Any leaks that are detected must be repaired. Once the grid has been converted to hydrogen, it must be checked again by searching for leaks above ground. A value lower than 10 ppm (of either CH_4 or H_2) is acceptable, regardless of the distance to the building. The leak survey may, for example, be carried out in the period from two weeks to three months after commissioning.

Purging, venting and flaring

When hydrogen pipelines are commissioned and decommissioned, they must be safely and effectively filled with or emptied of hydrogen by purging the pipeline. The purging procedure includes venting or flaring. Various experiments [4] [5] have been carried out to determine the required purging rate to fully achieve the desired result. The results are explained below.

Use nitrogen to prevent the formation of flammable mixtures in pipelines

The hydrogen distribution grid must be thoroughly purged before it can be used safely.
To prevent the formation of a flammable mixture in the pipe system (the flammability limits for hydrogen are 4-75% hydrogen in air), air is not purged with hydrogen and hydrogen is not purged with air. Pipes can be safely purged as follows:

- When commissioning a new, air-filled pipe, the pipe should first be purged with inert nitrogen gas. The nitrogen is then purged with hydrogen.
- When degassing a pipe section for maintenance or expansion works, the hydrogen should be purged with nitrogen.
- When commissioning an existing natural gas pipeline, the natural gas should be purged directly with hydrogen. Due to the absence of oxygen in the pipeline, which is filled with natural gas, it is unnecessary to purge it with inert nitrogen.

The studies began with the installation of two polyethylene test pipes, DN100 and DN200. A bridging pipe was also installed to test the effect of height differences (see figure 1).

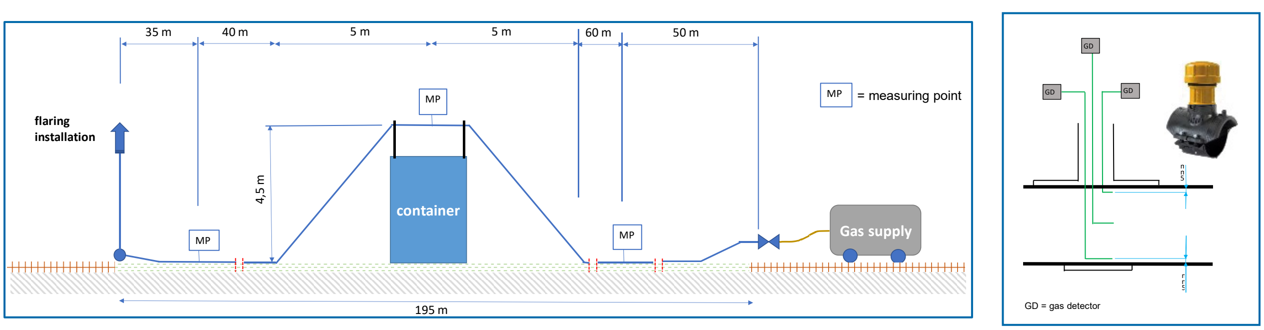

Figure 1 and 2: Test fixture and measuring points

Gas detectors were installed at various points in the pipes (see figure 2) and the gas concentration was measured during the purging of the pipe. Some measurements were also supported with CFD calculations. The survey showed that purging at a rate of 0.4 m/s is sufficient in all cases to:

- purge nitrogen with hydrogen
- purge hydrogen with nitrogen
- purge natural gas with hydrogen

However, a purging rate of 1 m/s is recommended, as this will reduce the volume of the hydrogen/nitrogen mixture that forms in the pipe. This hydrogen/nitrogen mixture will mix with the ambient air at the outflow point, which may lead to the formation of a flammable mixture. If venting is chosen, a higher purging rate will reduce the duration of the period in which a flammable mixture is present at the venting location. If flaring is chosen, a higher purging rate reduces the duration of the open flame. In all situations the purging time is reduced.

Venting and flaring

During purging activities, the purging gas must be discharged to the outside air. This may be done by venting or flaring. With venting, the gas to be vented is not ignited. With flaring, the gas is ignited, which results in a flame at the flaring location. Studies have primarily been carried out on behalf of Netbeheer Nederland [6] to assess the suitability of the standard techniques for use with hydrogen. These studies included both theoretical research (literature and CFD calculations) and practical research.

Venting can be carried out safely when purging:

- nitrogen with hydrogen
- natural gas with hydrogen
- hydrogen with nitrogen

A flame arrester is not required, as the risk of unintentionally igniting a hydrogen plume is very low. Flaring is greatly preferable when purging natural gas with hydrogen, as unburned natural gas has a much greater environmental impact (it is a greenhouse gas) than the CO_2 released when burning natural gas [5].

When venting hydrogen at a flow rate of up to 50 m^3/h, a minimum distance of 16 metres to the ignition source must be maintained. When venting hydrogen at 100 m^3/h, this distance must be at least 20 metres. If the flow rate is increased to 300 m^3/h, a distance of at least 35 metres must be maintained. The hydrogen concentration is $<$ 10% of the LEL beyond these distances and there is no risk of igniting the plume. These distances were determined using CFD calculations [6].
The outflow point of the venting system must be at least 2.5 metres above the ground. This eliminates the risk of igniting the hydrogen plume up to a height of around 2 metres above the ground. [6]

Flaring can be carried out safely

Flaring can be carried out safely when purging:

- nitrogen with hydrogen
- natural gas with hydrogen
- hydrogen with nitrogen

A flame arrester is not required [6]. When purging natural gas, the flame colour changes from yellow to colourless. This is a good indication that the purging process is complete. It was also observed that a hydrogen flame is more clearly visible in humid conditions than in dry conditions [5].

The presence of trees and bushes in the surrounding area must be taken into account when flaring. The required safe distances around the flaring location are the same as those for natural gas. This applies in situations where the energy contained in the hydrogen or natural gas to be flared is the same. If the flow rate for hydrogen is the same as the flow rate for natural gas, the radiation heat of the hydrogen flame will be lower.

Report [6] 'Flaring and venting of hydrogen' describes the flaring and venting of hydrogen/nitrogen mixtures as well as hydrogen/air mixtures, which are formed if air is used to purge pipes. Purging with air is not recommended, as the passage of flame into the distribution pipe cannot always be prevented.

A flame arrester as an extra safety precaution

The purpose of a flame arrester is to prevent the passage of flame into a pipe (light back). This may occur if the combustion rate is greater than the exhaust velocity of the gas/air mixture. The risk of light back is greater with hydrogen than with natural gas, due to the higher combustion rate and wider flammability limits of hydrogen.
The use of a flame arrester is an extra safety precaution in addition to purging with an inert gas. If air is present in the pipe that is to be purged despite the use of an inert gas, the flame arrester prevents light back. If air is purged with hydrogen or hydrogen is purged with air for any reason, a flame arrester must always be used.

Sectioning

Various techniques may be used to interrupt the flow of gas in the event of planned works or to repair defects. Fixed shut-off valves (ball valves, gate valves etc.) may be used, as well as temporary measures such as squeezing or stoppling. Research has been carried out to determine the suitability of these measures for use in a hydrogen distribution grid. The results are positive [7] [8]. Inflatable gas stoppers can also be used to temporarily close pipes. Their suitability for use with hydrogen is described below.

Inflatable gas stoppers can burst in some situations

When inflatable gas stoppers are used, a balloon is inserted into the pipe using a saddle installed on the pipe. The inflatable gas stopper is inserted and inflated, which blocks the flow of gas. Some leakage is permitted when using this closing method with natural gas, which can be used in distribution grids at up to 200 mbar. The use of multiple inflatable gas stoppers is mandatory in some cases. Although the inflatable gas stopper creates a complete seal, gas will still be present in the gas pipe for some time (see later in this section) if the pipe is blocked following a rupture. In the Netherlands this has not led to problems with natural gas in the past. It is important to keep sources of ignition away from the area around the outflow opening as a safety precaution. The suitability of inflatable gas stoppers for hydrogen grids was studied in HyDelta 2.0 [9]. The study investigated whether inflatable gas stoppers are capable of withstanding the ignition of a simulated gas leak and the extinguishing of a burning gas outflow. The use of inflatable gas stoppers for planned works and in response to incidents was studied. When carrying out planned works, an inflatable gas stopper is installed at around 1 metre from the working pit. When used in response to incidents, the distance may be up to 20 metres.
The measurements were carried out with both natural gas and hydrogen to allow a comparison to be made with the current situation. Table 1 shows the results of a direct ignition close to the outflow opening in the working pit. The source of ignition was present at the moment the gas leak was created. Table 2 shows the results of the delayed ignition of a gas/air mixture once a specific gas concentration had formed in the working pit.

Table 1. Direct ignition of a limited leak causes damage to the inflatable gas stopper

Pipe length (m)	Gas	Flow m³/h	Condition of the inflatable gas stopper	Observed combustion
1	Natural gas	0.15	Inflatable gas stopper burst due to burning gas.	Controlled
1	Hydrogen	0.45	Inflatable gas stopper damaged due to burning gas.	Controlled
20	Natural gas	0.20	No damage.	Controlled
20	Hydrogen	0.60	Inflatable gas stopper burst due to violent ignition and pressure wave in the pipe in 2 of the 3 measurements.	Violent

Table 2. Delayed ignitions do not adversely affect the inflatable gas stopper

Pipe length (m)	Gas	Flow m³/h	Gas conc. in the working pit (%)	Condition of the inflatable gas stopper	Observed combustion
1	Natural gas	3	9	No damage	Controlled
1	Natural gas	4	7	No damage	Controlled
1	Natural gas	7	14	No damage	Controlled
1	Natural gas	7	12	No damage	Controlled
1	Natural gas	7	14	No damage	Controlled
1	Natural gas	7.5	18	No damage	Controlled
1	Hydrogen	4	4	No damage	Powerful
1	Hydrogen	4	6	No damage	Powerful
1	Hydrogen	8	9	No damage	Powerful
1	Hydrogen	8	8	No damage	Powerful
1	Hydrogen	15.5	12	No damage	Powerful
20	Natural gas	4	5	No damage	Controlled
20	Natural gas	7	14	No damage	Controlled
20	Natural gas	7	9	No damage	Controlled
20	Natural gas	8	16	No damage	Controlled
20	Hydrogen	6	5	No damage	Powerful
20	Hydrogen	6	5	No damage	Powerful
20	Hydrogen	15	10	No damage	Powerful
20	Hydrogen	15	10	No damage	Powerful

When a pipe with a length of 20 metres is filled with hydrogen at a low flow rate (such as the tested 0.6 m^3/h), for example due to a leak in the closing device, this results in violent ignition. The tested inflatable gas stopper was incapable of withstanding this. A fixed shut-off valve, a stopple or a squeezed-off pipe would be less affected. The use of a double inflatable gas stopper in combination with purging with nitrogen can reduce the risk that the inflatable gas stopper will become dislodged. The double inflatable gas stopper ensures that the leaking gas cannot flow into the pipe. Purging with nitrogen ensures that hydrogen is rapidly purged out of the pipe once the balloon has been inflated. However, this additional measure is unnecessary if the length from the inflatable gas stopper to the outflow opening is only 1 metre, as the gas will rapidly dissolve in the ambient air. It is of course important to keep sources of ignition away from the area in and around the working pit at all times.

It is possible to extinguish a gas fire with an inflatable gas stopper

A natural gas leak (23 m^3/h) was ignited in a test fixture. The gas flow was interrupted and the gas fire extinguished using an inflatable gas stopper at a distance of 20 metres from the outflow opening. The extinguishing process continued gently; the natural gas in the pipe burned in a controlled manner and the outflow of exhaust gasses and inflow of combustion air kept each other in balance.
A hydrogen leak (80 m^3/h) was then ignited. The gas flow was interrupted and the gas fire extinguished using an inflatable gas stopper at a distance of 20 metres from the outflow opening. Once the inflatable gas stopper was inflated, the flame was intermittently visible/audible and invisible/inaudible in the area around the outflow opening. The extinguishing process proceeded gently; the hydrogen in the pipe burned out in a controlled manner and the outflow of exhaust gasses and inflow of combustion air proceeded in succession.
The ignition of hydrogen at a high flow rate (> 80 m^3/h, velocity > 0.2 m/s) did not adversely affect the inflatable gas stopper. The flame did not move into the pipe.

Prolonged presence of flammable hydrogen/air mixture following sectioning in response to a pipe rupture

Once a damaged pipe has been sectioned using fixed shut-off valves or a temporary measure, the pipe rupture is excavated and exposed. Some gas will still be present in the pipe. The hydrogen will flow out from the top of the pipe and the air will flow in at the bottom due to the differing densities of hydrogen and air. This will cause the concentration in the pipe to gradually decrease from 100% to zero. Due to the wider flammability limits for hydrogen (75%-4%) compared to natural gas (15%-5%), a flammable mixture will be present in the pipe for longer with hydrogen. The risk of ignition is also higher for hydrogen in this situation, as an ideal mixture will form at a certain moment. The minimum ignition energy of an ideal mixture is much lower for hydrogen than natural gas (0.02 mJ versus 0.3 mJ). An accidental ignition of a hydrogen/air mixture can also be more violent than a natural gas/air mixture.
The study carried out [10] showed that a flammable mixture forms in the pipe almost immediately after the sectioned pipe is opened. In the study, this flammable mixture flowed out of the measurement stand over an extended period. Measurements were carried out on DN100 and DN200 pipes of 200 metres. The filled pipes were closed off at one end, and the other end remained fully opened. With the DN100 pipe, a flammable mixture flowed out of the pipe for more than 30 minutes, and for more than 90 minutes with the DN200 pipe. The conclusion is that a considerable time will pass before the hydrogen naturally ventilates out of a pipe that has been fully opened at one end.

Purging with nitrogen and measuring gas concentration are a solution

Engineers must take precautions to deal with the presence of a flammable hydrogen/air mixture in the pipe once the gas flow has been stopped. The following recommendations apply in situations where the pipe is shut off at a large distance from the outflow opening:

- The pipe should be purged with nitrogen from the point of shut off towards the rupture.
- Gas concentration measurements should be carried out at the outflow opening once the pipe leak has been excavated. The repair can only be started once the concentration at the outflow opening has dropped to < 10% of the LEL.

Discussion

General

The term ‘natural gas’ is used throughout this article. The tests carried out with natural gas used Dutch natural gas (L gas/G25). The composition of this gas deviates somewhat from that of the type of natural gas used in most countries (H gas/G20/100% CH_4). This is due to the unique composition of the natural gas originally extracted from the Groningen gasfield in the Netherlands. Dutch natural gas contains 81% methane, around 4% higher hydrocarbons, 14% nitrogen and 1% carbon dioxide. The natural gas type affects the stated theoretical factors of 1.3 to 3.0 for the difference between the leakage rates of hydrogen and natural gas. For G20, these theoretical factors are 1.25 to 2.8. The average factor determined based on practical measurements of leaks was 1.8. As this is an average value, and because the theoretical values do not differ greatly, it is reasonable to also use the factor of 1.8 for G20. The factor will be slightly lower for G20 in practice. The differences between G20 and G25 are less important for the other studies described in this article.

This article covers the reuse of main lines and service lines. The gas stations, gas meters and consumer pressure regulators and gas equipment used by end users are not covered. Consumer pipe materials may be suitable for reuse. Gas stations and pressure regulators may also be (partly) reusable following a specific assessment. However, gas meters and equipment of end users must be replaced when converting to 100% hydrogen. All these topics are covered in studies carried out as part of HyDelta.

Venting and degassing service lines

If service lines are not vented, only the air in the first part of the service line will be replaced by nitrogen due to the (limited) difference in density. This means the service line must also be purged with nitrogen. The pipe may be vented at the measuring point next to the gas meter, for example.
When degassing the main lines with nitrogen, hydrogen will remain in the connected service lines. Where these pipes are connected at the top, hydrogen can slowly mix with the nitrogen in the main line after the purging process due to diffusion. With side junctions, the hydrogen will also mix with the nitrogen in the main line [4]. This is primarily due to the differing densities of nitrogen and hydrogen.

Inflatable gas stoppers

In the described study, a single type of inflatable gas stopper was investigated in a single pipe diameter.
The behaviour of a second type of inflatable gas stopper and another pipe diameter (DN100) will be studied in HyDelta 3.0. The effectiveness of block and bleed in combination with nitrogen with inflatable gas stoppers will also be studied.

Conclusions

The most important conclusions of the described studies are:

- A distribution grid that is leak tight for natural gas will also be leak tight for hydrogen.
- For low natural gas leakage rates (less than 1 dm^3/h), the leakage rate of hydrogen is 1.8 times greater.
- A purging rate of 0.4 m/s is sufficient to fill a pipe with hydrogen or to remove hydrogen from a pipe. A rate of 1.0 m/s is recommended, because this reduces the time for purging, venting and flaring. Purging with nitrogen as an intermediate step is required in some situations.
- Venting and flaring hydrogen can be carried out safely.
- Existing closing methods used for natural gas can be used in hydrogen distribution grids.
- If a hydrogen pipeline is closed at one end and the other end is open to the air (repair after incident), a flammable mixture will be present in the pipe for a prolonged period.
- The ignition of a limited volume of hydrogen in a pipe (20 metres, Ø 160 mm) that is closed at one end with the other end open to the air will result in a violent pressure wave, which may cause damage to materials and injury to engineers.

Provided that appropriate measures are taken, natural gas distribution grids are suitable for conversion to hydrogen distribution grids. Some of the recommended measures include:

- Assess the leak tightness by searching for leaks above ground before and after converting main lines and service lines.
- Assess the leak tightness of every service line using a pressure drop test before hydrogen is supplied to the consumer.
- Install an Excess Flow Valve at the junction between the main line and service line.
- Prevent the formation of a hydrogen/air mixture in piping systems by purging with nitrogen for all types of activity.
- When using inflatable gas stoppers to respond to incidents, use a double inflatable gas stopper in all situations in combination with the purging of hydrogen with nitrogen.
- In addition to the use of nitrogen, a flame arrester should be used when venting and flaring.

These measures will require modifications to working procedures.

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