# HyDelta

## WP 1C Pipes and indoor installations (components)

D1C.1a – Entry of air into a hydrogen pipeline in case of a pipe rupture

Status: final

This project has been co-funded by TKI Energie as part of the Grant for Top Consortia for Knowledge and Innovation (TKIs) through the Ministry of Economic Affairs and Climate Change, under reference number TKI2020-HyDelta.

# Document summary

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**Document history**

| Version | Date | Author | On behalf of | Summary of the changes |
|---|---|---|---|---|
| 1 | 02.04.2021 | Sander Lueb | Kiwa Technology | For discussion of raw data and conclusions |
| 2 | 18.06.2021 | Sander Lueb | Kiwa Technology | Elaboration of version 1 |
| 3 | 05.07.2021 | Sander Lueb | Kiwa Technology | Processing comments made by EAG Group |
| 4 | 22.07.2021 | Sander Lueb | Kiwa Technology | Processing comments made by Supervisory Group and OGH2 |
| 5 | 10.11.2021 | Sander Lueb | Kiwa Technology | Addition of names in table document review |

**Distribution level**

| Distribution level | | |
|---|---|---|
| **PU** | Public | X |
| **R1** | Limited to<br>• Partners including Expert Assessment Group<br>• Other participants of the project including Sounding Board<br>• External entity specified by the consortium | |
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| **R3** | Limited to<br>• Partners including Expert Assessment Group | |

**Document review**

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# Executive summary

As part of the national research programme HyDelta, a study was carried out into the effects of air entering a hydrogen-filled distribution pipeline in the event of a pipe breakage. The research described in this report is part of the Work Package 1C "Pipes and indoor installations".

As requested by the OGH2 (OnderzoeksGroep or Research Group H2), research question 187 "*How can an existing gas distribution pipeline be safely decommissioned as a natural gas pipeline and (simultaneously) commissioned as a hydrogen pipeline during the conversion to a hydrogen network and what are the associated costs?*" has been supplemented with an additional research question. During that research study, distribution pipes DN 100 and DN 200 were filled with hydrogen. The results in the context of research question 187 are described in a separate report.

The research as described in this report is complementary to the research questions posed in the context of HyDelta WP1C.

*Aim and testing approach*
The aim of this research is to determine to what extent air enters a hydrogen distribution pipeline in the event of a pipe rupture. This was done by filling distribution pipes with a diameter of DN 100 and DN 200 with hydrogen. The concentrations (gas/air ratio) were measured in the pipes both with and without shielding of the entry opening. The pipes were filled with hydrogen and then opened on one end.

*Results*
The test programmes showed that after creating the leakage (opening a valve), hydrogen flows out of the pipe and air enters immediately. Furthermore, an explosive mixture was found almost immediately after the entry of air in both the DN 100 and the DN 200 pipe. This explosive mixture remained during the full measurement time of 90 minutes. The outflow of hydrogen and the entry of air is caused by the difference in density between hydrogen and air.

The inflow of air into the DN 200 pipe was greater than the air inflow into the DN 100 pipe. Measuring at a distance of 25 metres from the opening: the explosive mixture formed more rapidly when testing the DN 200 pipe as compared to the smaller DN 100 pipe. The resistance of the hydrogen outflow and the resistance of the air inflow are smaller in a larger diameter compared to a smaller diameter.

Like during the measurements without shielding there was hardly any wind and the effect of wind was therefore not measurable.

The measurements show that an explosive mixture is formed almost immediately in an open depressurised pipe filled with 100% hydrogen. The release of hydrogen and the entry of air is caused by the difference in density between hydrogen and air. Comparing this to natural gas: natural gas is 9 times more dense than hydrogen. It is expected that, when using hydrogen, an explosive mixture will form in a depressurised pipe faster and over a greater length than when natural gas is in the pipe.

*Recommendations*
It is advisable to also investigate the effect of air entering a pipe when repairing a rupture in a natural gas-filled pipe in order to better understand the risks with hydrogen. In that additional study, it is

also advisable to consider the influence of the opening’s size and the length between the opening and the inflatable stopper.

Further research is needed to determine the consequences of an explosive hydrogen mixture igniting in a blocked section of the gas network. It can be determined whether an inflatable stopper offers sufficient stability to permanently block the gas flow in the event of an explosion. It is recommended to carry out these ignition tests with hydrogen and with natural gas.

# Table of contents

# 1. Introduction

## 1.1 General

This study has been carried out within the framework of the national HyDelta research programme. The programme focuses on integrating hydrogen safely into the existing infrastructure for gas transport and distribution, and aims to remove barriers that would limit or stop the upscaling of hydrogen. The complete research programme is divided into work packages. For an explanation of these different work packages, see www.hydelta.nl.

## 1.2 Problem definition

In the event of a pipe rupture in a hydrogen distribution pipeline, it is likely that gas pipe bladders, or inflatable stoppers, will be placed to repair the leak. During excavation work on the broken pipe, there is a chance that air enters the depressurised pipe. If that happens, it will create an explosive mixture inside the pipe. Kiwa Technology has carried out a study commissioned by Netbeheer Nederland into the entry of air into open hydrogen pipes of indoor installations (reference report VGI/1337/Sal). No such study has been carried out for distribution pipelines.

## 1.3 Research question in HyDelta

The OGH2 (*OnderzoeksGroep H2* or Research Group H2) requested that the aspect of mixing hydrogen with air in the event of a pipeline rupture be included in the implementation of research question 187. It has been established for research question 187 that pipelines filled with natural gas can be flushed directly with hydrogen. This was done by filling distribution pipelines DN 100 and DN 200 with hydrogen. The results within the framework of research question 187 are described in a separate report. The research described in this report is supplementary to the research questions asked, including question 187 as part of HyDelta WP1C (see Appendix I for an overview of the questions from WP1C).

This additional research was submitted to the Steering Group of HyDelta for execution, approved and subsequently implemented.

# 2. Objective

The aim of this research study is to determine to what extent air will enter a hydrogen distribution pipe in case of a pipe rupture, to what extent an explosive mixture will arise, and how this will develop over time.

# 3. Method

## 3.1 General working method

The execution of this study was coordinated with a guidance group and sparring group. Both groups consist of participants from the regional network operators (see Appendix II). The agreed test programme is included in Appendix III. The main components are highlighted below.

## 3.2 Measuring points

Measuring points for measuring the hydrogen concentration were located at approximately 1, 10 and 25 metres from the opening. At each distance, a measuring point was placed at the top and bottom of the pipe. The extracted gas/air mixture (for the concentration measurement) was fed back into the pipeline in order to avoid disruption of air entry as much as possible.

## 3.3 Duration of measurements

The measurements were devised on the assumption that network operators will not leave a ruptured pipeline open for long (after the gas supply to the rupture has been stopped[1]). A time span of 1 hour is realistic. Each series of measurements was ultimately continued for 1.5 hours. The first minutes were measured every 30 seconds, then every 2 minutes until 60 minutes. After one hour, the measurements were taken every 10 minutes.

## 3.4 Effects of wind

In practice, the amount of wind obviously influences the measurements. The stronger the wind, the faster the gas and air will mix in the pipe. In order to exclude the effect of wind *and* to possibly provide insight, measurements are taken both with and without shielding.

## 3.5 Test programme for measurements

Four series of measurements were carried out on hydrogen-filled pipes (length approximately 200 metres, pressure approximately 100 mbar) that were opened on one side. These were:
- 1 measurement series DN 100 with shielding by a tent
- 1 measurement series DN 100 without shielding
- 1 measurement series DN 200 with shielding by a tent
- 1 measurement series DN 200 without shielding

During the measurements, the decrease in hydrogen concentration was measured. See Annex VI for an overview of the measuring equipment used.

## 3.6 Test pipe

No inflatable stopper was placed at 25 metres during the measurements. This was because a closed shut-off valve was located 200 metres from the leak. A layout drawing of the test pipe is provided in Appendix IV. See Appendix V for photographs.

Remarks:
The DN 200 pipe is a PE 100 SDR 17 with an external diameter of 200 mm and an internal diameter of 177 mm. The DN 100 pipe is a PE 100 SDR 17.6 with an external diameter of 110 mm and an internal diameter of 97.4 mm.

[1] When there is still gas escaping from the fracture, no air will enter.

# 4. Result

This chapter contains the results of the measurements that were carried out. The results of the DN 100 are recorded in section 4.1 and the results of the DN 200 are in section 4.2. Section 4.3 gives an overview of all measurements indicating if a flammable and/or explosive mixture is formed.

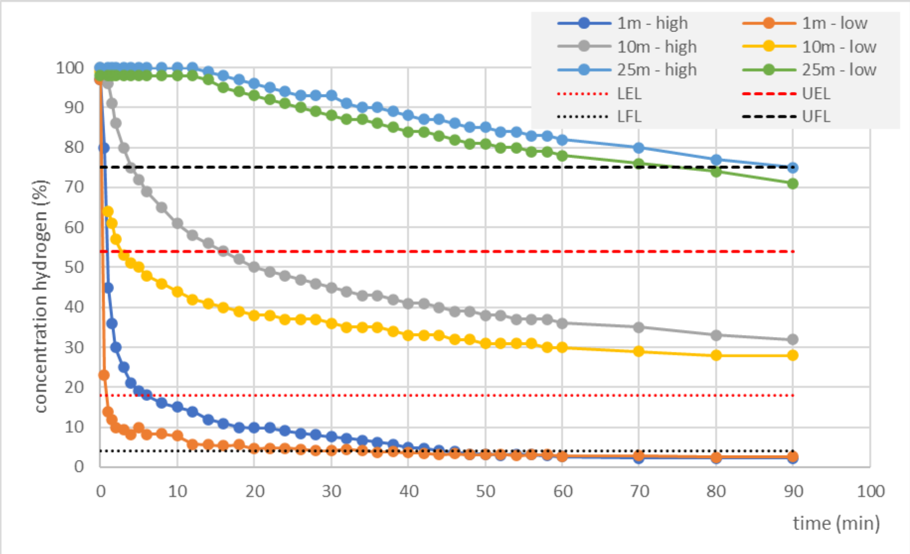
*Table 1. Performed measurements and average weather conditions*

| Description | Date | Average wind speed (m/s) | Average outside temperature (°C) |
|---|---|---|---|
| DN 100 without shielding | 02.03.2021 | 1.4 | 14.4 |
| DN 100 with shielding | 03.03.2021 | 3.8 | 7.9 |
| DN 200 without shielding | 03.03.2021 | 2.6 | 14.1 |
| DN 200 with shielding | 03.03.2021 | 1.2 | 12.0 |
| | | | |

Notes to the graphs and tables in 4.1 to 4. 3
Flammability limits of hydrogen in air; 4 - 75%.
Explosion limits of hydrogen in air; 18 - 54%

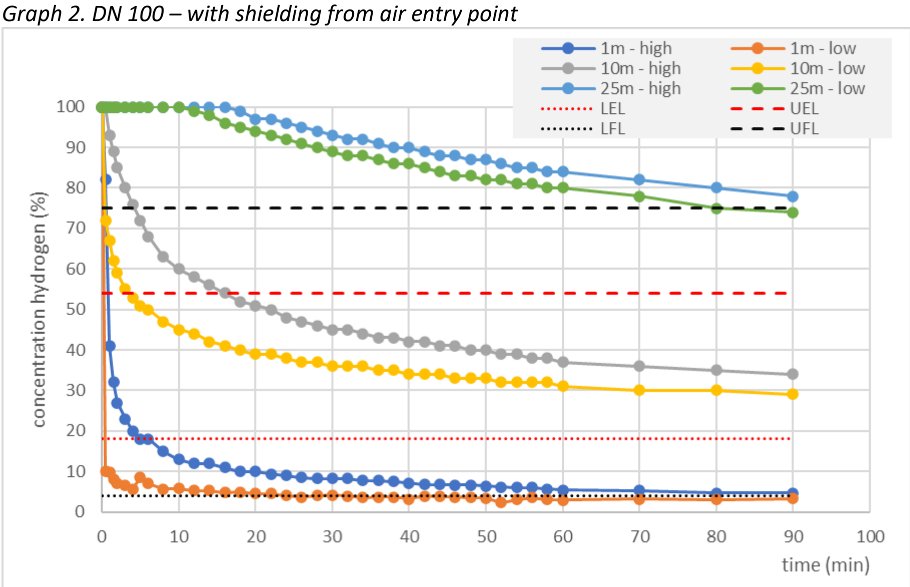
## 4.1 Measurements DN 100

*Graph 1. DN 100 – without shielding from air entry point*




Within 1 minute, an explosive mixture occurs at a distance of 1 metre from the leak (see orange and dark blue line). Within 5 minutes, an explosive mixture occurs at a distance of 10 metres from the leak (see grey and yellow line). After 1.5 hours, there is no explosive mixture present at a distance of 25 metres from the leak (see green and light blue line). The concentrations of hydrogen at the top of the pipe are higher than at the bottom: this can be seen by the differences in the measuring points “high” and “low”.

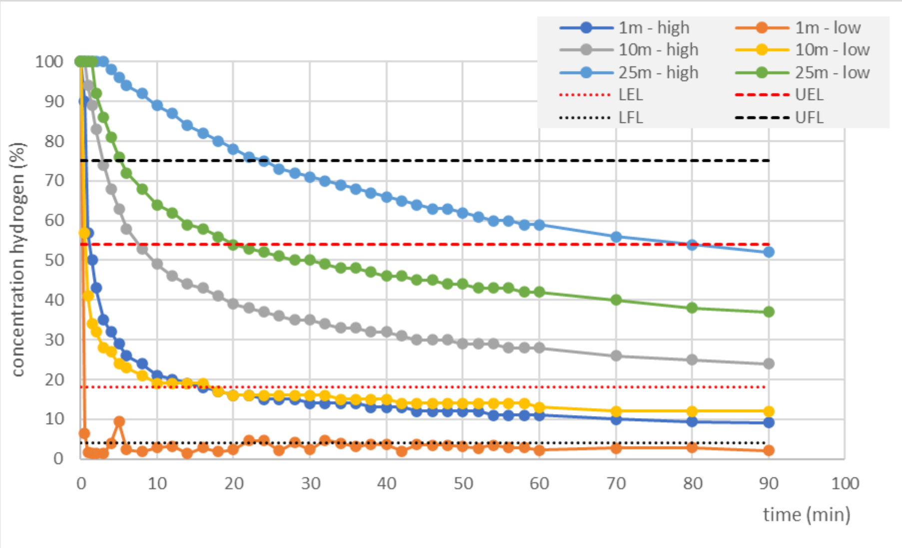
*Graph 2. DN 100 – with shielding from air entry point*




When measuring the DN 100 pipe with shielding, the results are almost identical to the results obtained without shielding. The mixture in the pipe at a distance of 1 metre from the leakage is flammable throughout the entire measuring period (90 minutes). At a short distance from the leakage (in the open air), the concentration of hydrogen is less than 0.1% (measuring point not included in the graphs). The concentrations of hydrogen inside the pipeline are higher at the top than at the bottom.

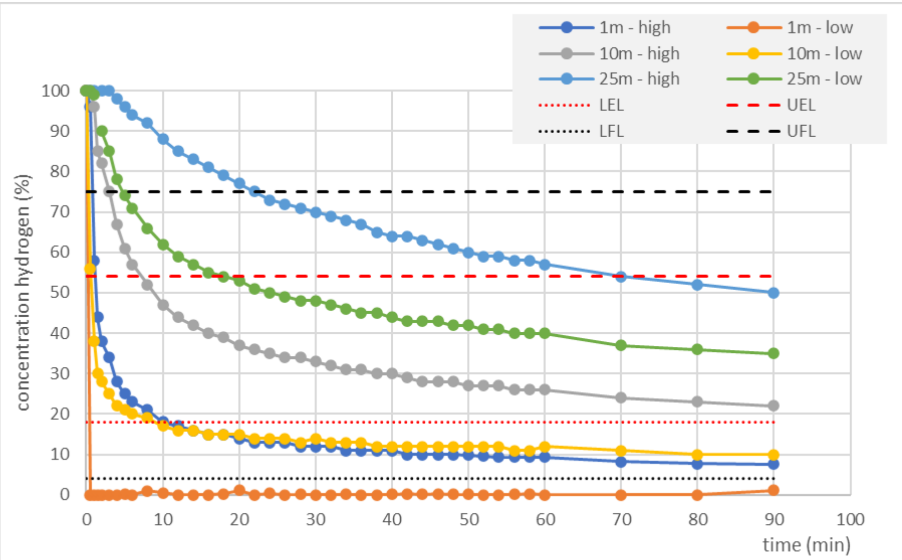
## 4.2 Measurements DN 200

*Graph 3. DN 200 – without shielding from air entry point*




Within 1 minute, an explosive mixture occurs at a distance of 1 metre and 10 metres from the leak (see orange, dark blue, yellow and grey line). Within 20 minutes, an explosive mixture occurs at a distance of 25 metres from the leak (see green and light blue line). The concentrations of hydrogen at the top of the pipe are higher than at the bottom, and the differences with the DN 100 pipe are greater: this can be seen by the differences in the measuring points “high” and “low”.

*Graph 4. DN 200 – with shielding from air entry point*




When measuring the DN 200 pipe with shielding, the results are almost identical to the results obtained without shielding. The mixture in the pipe at a distance of 1 metre from the leakage is flammable throughout the entire measuring period (90 minutes). At a short distance from the leakage (in the open air), the concentration of hydrogen is almost continuously less than 0.5% (measuring point not included in the graphs). The concentrations of hydrogen inside the pipeline are higher at the top than at the bottom.

## 4.3 Overview of flammable and explosive mixtures in the pipe

Flammable and/or explosive mixtures are created when air enters the hydrogen-filled pipe. The times at which these mixtures occur are shown in the table below.

*Table 2. Overview of moments when a flammable and/or explosive mixture is present in the pipeline.*

| DN | Shielding | Formation of combustible mixture? | | | Formation of explosive mixture? | | |
|---|---|---|---|---|---|---|---|
| | | 1 m | 10 m | 25 m | 1 m | 10 m | 25 m |
| 100 | without | yes, from start to 46 min | yes, from 1 min to end | yes, after 70 min | yes, to first 5 min | yes, from 3 min to end | no |
| 100 | with | yes, from start to end | yes, from start to end | yes, after 80 min | yes, to first 6 min | yes, from 10 min to end | no |
| 200 | without | yes, from start to end | yes, from start to end | yes, from 5 min to end | yes, from 1 min to 16 min | yes, from 0.5 min to end | yes, from 20 min to end |
| 200 | with | yes, from start to end | yes, from start to end | yes, from 5 min to end | yes, from 1 min to 12 min | yes, from 0.5 min to end | yes, from 16 min to end |
| The duration of the measurements was 90 minutes per measurement series. The time “from” is the time from opening the shut-off valve at the air inlet. | | | | | | | |

# 5. Conclusions

Immediately after the leak has occurred (valve opened), hydrogen flows out and air enters the DN 100 and DN 200 pipes.

In both the DN 100 and DN 200 pipe, an explosive mixture occurs almost immediately after the entry of air. An explosive mixture remains in the pipes at each measuring point with both diameters throughout the measuring time. The outflow of hydrogen and entry of air is caused by the difference in density between hydrogen and air[2].

The concentrations of hydrogen at the top of the pipe are higher than at the bottom, where the concentration differences in the DN 200 pipe are greater in comparison with the DN 100 pipe.

In the DN 200 pipe, the air flows into the pipe more rapidly than in the DN 100 pipe. Therefore, at a distance of 25 metres from the opening, an explosive mixture is formed more quickly in the DN 200 pipe than in the DN 100 pipe. The resistance of the hydrogen exit flow and the resistance of the air entry flow are smaller with a larger diameter compared to the smaller diameter.

The effect of wind cannot be measured properly because the wind speed during the measurements without the shielding was too light to have any influence at all.

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Density of hydrogen is 0.0899 kg/m3 (n)
Density of air is 1.293 kg/m3 (n)
Density of natural gas is 0.83 kg/m3 (n)

# 6. Recommendations

Based on the research carried out, the following additional measurements are recommended.

Perform comparable measurements with natural gas
The measurements show that in an opened, depressurised pipe filled with 100% hydrogen, an explosive mixture occurs almost immediately. The outflow of hydrogen and entry of air is caused by the difference in density between hydrogen and air. The difference in density between natural gas and hydrogen is a factor of 9. It is therefore very likely that an explosive mixture will form less quickly when natural gas is used. It is advisable to do research into the effect of air entering a pipeline when repairing a break in the pipeline with natural gas in order to be able to better identify the risks with hydrogen.
In a supplementary research study, it is also advisable to consider the influence of the opening's size and the length of the opening to the inflatable stopper. In the study that was carried out, the research only looked at a full opening and a length of 200 metres. Smaller openings and a shorter length between the orifice and the inflatable stopper can be used in practice.

Ignition tests with hydrogen and natural gas
Based on the measurements carried out, it has been established that there is a chance of ignition or explosion in the pipeline. The expectation is that, in comparison with natural gas, an explosive mixture will develop more quickly and therefore over a greater length in a hydrogen-filled depressurised pipe. In order to determine what the consequences might be in the event that such an explosive mixture is ignited in a closed-off pipe section, further research is advisable. In doing so, it is preferable to actually use a pipe bladder and choose a distance from bladder to inlet opening that corresponds to the maximum distance as that is applied in practice. This enables the researchers to establish whether, in the event of an explosion, a bladder offers sufficient stability to block the gas flow permanently. It is recommended to carry out these ignition tests with hydrogen as well as with natural gas.

# Appendix I Summary of questions HyDelta WP1C

The following questions are addressed in this work package.

- Question number HyDelta 187: Research study into the safe commissioning and decommissioning of pipeline sections in hydrogen distribution during conversion to a hydrogen network and the associated costs.
- Question number HyDelta 124: Research study into the implementation of the strength and density tests.
- Question number HyDelta 135: What is the effect of the existing gas network on the quality of hydrogen in distribution and transport? (Such as dust, dirt and THT)
- Question number HyDelta 185: Gas pressure regulator in homes: What is the risk if it is not adapted?
- Question number HyDelta 101: Research study into the risks related to existing gas installations (in customers' homes) when converting from natural gas to 100% hydrogen.
- Question number HyDelta 61: How do the developments of all components that are suitable for 100% hydrogen in the distribution network (incl. connections), at the indoor installation and in the gas consumption appliances inside homes fit together, so that the whole chain is coordinated?
- Question number HyDelta 55: What will the conversion to a hydrogen network look like?

# Appendix II Composition overview of guidance group and sparring group sub-question 187 and supplementary entry of air

*Table 3. Composition of guidance group and sparring group*

| Name | Employer | Guidance group | Sparring group |
|---|---|---|---|
| D. Nieuwenhuizen | Stedin | | V |
| H. Smit | Enexis | | V |
| W. Koppenol | Enexis | V | V |
| W.R. Nispeling | Alliander | | V |
| R. den Hartog | Westland Infra | V | V |
| J. Jonkman | Rendo | V | V |
| R. Scholten | Rendo | V | V |
| C. Lock | Kiwa Technology | V | V |
| S. Lueb | Kiwa Technology | V | V |
| *The guidance group has been assigned a more active role in the implementation of the sub-study compared to the sparring group. The sparring group is involved in setting up the test programme and assessing the draft reports.* | | | |

# Appendix III Memo about the test programme for mixing hydrogen with air

# Memo

| | |
|---|---|
| Bestemd voor: | Sparringsgroep deelvraag 187 WP1C |
| onderwerp: | Aanvulling diffusie op testprogramma deelvraag 187 spoelen_V2 |
| van: | Sander Lueb |
| datum: | 26 februari 2021 |

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In de memo d.d. 5 februari 2021 is het testprogramma opgenomen m.b.t. het spoelen van aardgasleidingen rechtstreeks met waterstof.

Er is een verzoek van Pascal te Morsche (vanuit OGH2) gekomen welke mogelijk gecombineerd kan worden met de metingen in het kader van deelvraag 187 uit WP1C. Tijdens overleg met de sparringsgroep en begeleidingsgroep op 10 februari is afgesproken dat Kiwa een voorstel gaat opstellen.

Verzoek
*Vanuit de OGH2 doet Kiwa (Henk Salomons) op dit moment onderzoek naar diffusie van waterstof, als je een met waterstof gevulde binnenleiding afkoppelt en open laat staan. Dus geen flow, maar 'stilstaand' gas, hoe snel vermengen lucht en waterstof dan in de leiding en leidt dat tot risicovolle mengsels?*
*Voor 16 en 23 mm lijkt dat nu mee te vallen, weinig vermenging.*

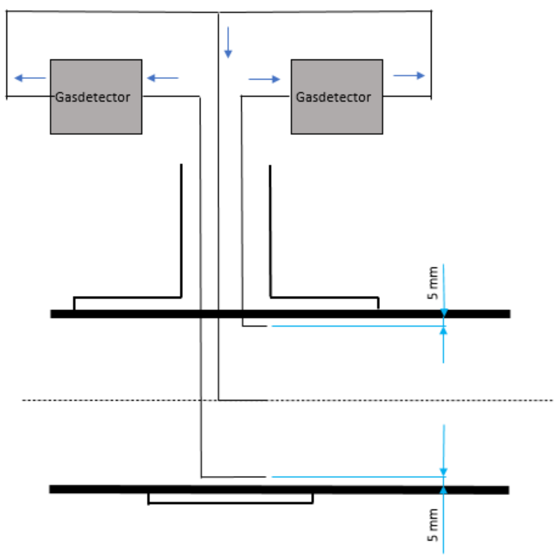
*Met regelmaat komt de vraag voorbij, of we deze proef ook niet moeten doen voor grotere leidingen. Bijvoorbeeld bij een leidingbreuk, wordt de hoofdleiding drukloos en kan er lucht in de leiding komen. Hoe snel gaat dat?*
*Op het Kiwa terrein liggen nu de 200 en 110 PE leidingen, die kun je daarvoor gebruiken.*

**Bij deze dit voorstel;**
Het vertrekpunt van de spoelmetingen zijn met aardgas gevulde leidingen. De concentratie toename van waterstof wordt vastgesteld aan de hand van aardgasdetectoren (afname van aardgasconcentratie).
Na afloop van de spoelmetingen zijn de PE leidingen 200 en 110 mm gevuld met waterstof. Daarna starten de metingen in het kader van diffusie. Ten behoeve van de diffusiemetingen wordt op 1, 10 en 25 meter afstand[1] van de inlaat meetpunten ten behoeve van een waterstofmeting aangebracht (meetpunt bovenin en onderin de leiding). Na afloop van de spoelmetingen word de inlaat in contact gebracht met de buitenlucht.
De meetapparatuur werkt door middel van aanzuiging van het gas. Het afgezogen gas wordt tussen de hiervoor genoemde meetpunten weer in het leidingsysteem gebracht, zie onderstaande figuur.
De concentratie waterstof wordt iedere 2 minuten opgenomen.

De tijdsduur van de diffusiemetingen is één uur (zie toelichting verderop). Er worden vier meetseries uitgevoerd. Twee met de 200 mm en twee met de 110 mm leiding. Na de meting wordt de leiding weer aardgasvoerend gemaakt door het toevoeren van aardgas (door toepassing van een affakkelinstallatie met vlamdover).

Circulatie vanwege afzuiging;
Door het afzuigen en weer inbrengen van gas krijg je inderdaad wat circulatie. In het veld zal er als gevolg van wind ook een bepaalde menging plaats vinden. Bij deze metingen is  het niet persé de bedoeling om de gelaagdheid van concentraties in beeld te brengen, maar om te bepalen tot welke afstand zich een explosief mengsel vormt.  Waterstofstofsensoren zonder aanzuiging hebben wij op dit moment niet in ons bezit.

[1] *Er is al een aftakking op 1 meter aanwezig. De aftakkingen op 10 en 25 meter zullen nog aangebracht worden.*




<u>Tijdsduur</u>
De  metingen zijn bedacht met als achtergrond een leidingbreuk en dat netbeheerders een breuk niet langdurig open laten liggen (nadat de gastoevoer naar de breuk is gestopt). Vanwege het niet langdurig open laten liggen is er voor 1 uur gekozen.   Het vormen van het explosief mengsel zal plaats gaan vinden na het zetten van de blazen.  De vraag die we wilden beantwoorden; kan er lucht instromen en hoe snel gaat dat? De voorgestelde metingen van 1 uur geven daarin een eerste inzicht, mochten de metingen daar aanleiding voor geven zullen we de tijdsduur gaan verlengen. De verwachting (op basis van metingen uitgevoerd met een gasmeter) is  dat waterstof snel zal uittreden.

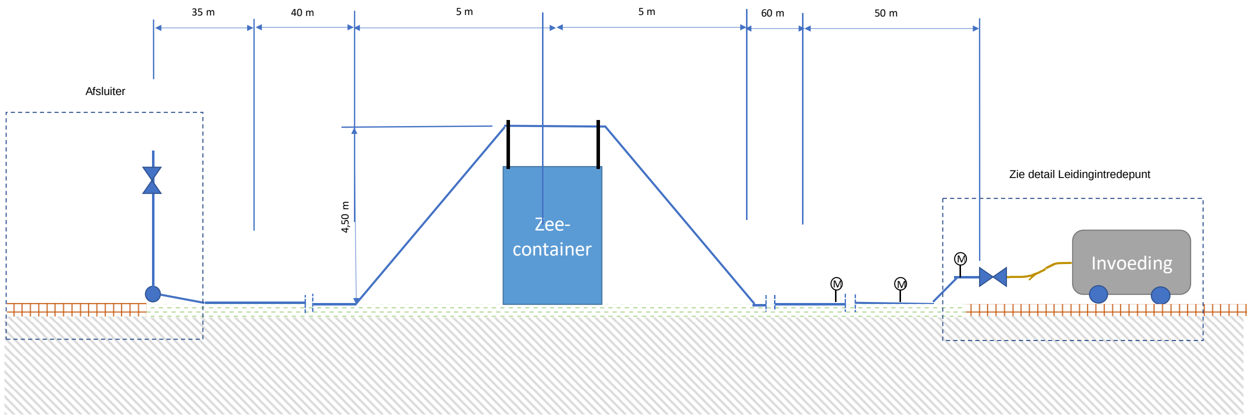
<u>Effecten wind</u>
Om de opening wordt bij enkele metingen een afschermende tent geplaatst. Desondanks worden weersomstandigheden tijdens de metingen gelogd (windsnelheid, windrichting en temperatuur).
In praktijk heeft de mate van wind uiteraard invloed op de metingen. Hoe harder het waait des te sneller zal er menging van gas en lucht in de leiding plaats vinden.  Door bij de metingen een tent om de inlaat  te plaatsen kijk je zoveel als mogelijk naar het werkelijk diffusie-proces. Stel dat er dan al over grote lengte een explosief mengel wordt gevormd binnen bijvoorbeeld 30 minuten dan zal dat bij aanwezigheid van wind nog sneller gaan. We stellen dus de mate van diffusie vast.  Vandaar dus het plaatsen van de tent.

We hadden 4 meetseries voorgesteld (2 aan 110 en 2 aan 200). Om het effect van (de dan heersende) wind inzichtelijk te krijgen stellen we nu het volgende voor:
- 1 meetserie 110 met afscherming door een tent.
- 1 meetserie 110 zonder afscherming
- 1 meetserie 200 met afscherming door een tent.
- 1 meetserie 200 zonder afscherming

De meerkosten voor deze werkzaamheden (voorbereidingen, metingen en rapportage) zijn 5.500 Euro (ex. BTW). Vooralsnog is echter de verwachting dat deze kosten binnen het gehele budget van WP1C uitgevoerd kunnen worden.

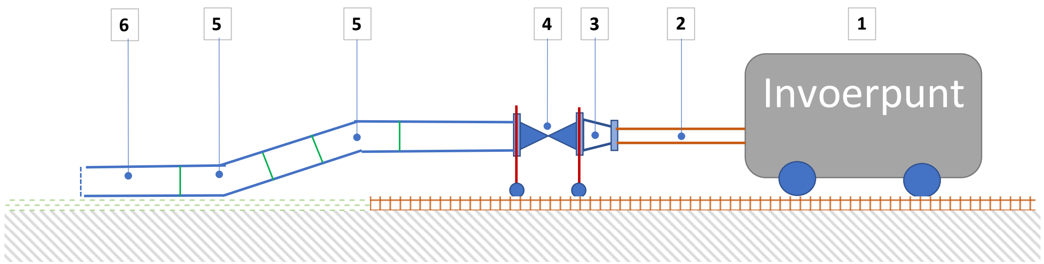
# Appendix IV Detailed drawings of the test pipeline

**Total route**




Measuring points (M) for measuring the concentration of hydrogen at 1, 10 and 25 metres from the shut-off valve after the entry point (not to scale). The entire test pipeline is filled with hydrogen.

**Details of pipe entry point**




1 Mobiel districstation
2 Flexibele aansluitslang
3 Verloop 4 inch - 8 inch
4 Schuifafsluiter DN 200
5 Bocht 22 gr - R 3,5 D
6 PE 200 - SDR 17

In addition to the DN 200 test pipe shown above, a DN 100 test pipe was installed with the same pipe layout.

Components 1, 2 and 3 were removed after filling the pipe with hydrogen. The valve (4) was then fully opened to simulate the leakage (open outflow).

# Appendix V Photos of the test rig


Entry points and inflow side of the bridge pipe


Bridge pipe and outlet side bridge pipe

The applied shielding around the opened valve

# Appendix VI Measuring equipment used

| Description | Manufacturer and type | Kiwa no. |
|---|---|---|
| Hydrogen detector | Riken Keiki NP 1000 | 114632 |
| Hydrogen detector | Riken Keiki NP 1000 | 114633 |
| Hydrogen detector | Riken Keiki NP 1000 | 114634 |
| Hydrogen detector | Riken Keiki NP 1000 | 114635 |
| Hydrogen detector | Riken Keiki NP 1000 | 114636 |
| Hydrogen detector | Riken Keiki NP 1000 | 114638 |