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# TP3-12 433 Validating a dynamic grid model with tracer gas injection and analysis

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## Abstract

Commissioned by Liander, the Dutch research institute TNO has developed a dynamic computer model of its gas grid. This model provides an insight how gas predictively flows through this grid, and is one of the building blocks toward making a smart grid. A combination of data from a variety of already present measuring devices, including flowmeters, pressure and temperature sensors, as well as information from static modelling software, was used to build this dynamic model. To validate the dynamic model a tracer gas test was conceived and executed. During this field test a traceable gas was injected in the gas grid, and analysers were attached to two gas pressure regulating stations further along the network to detect it. The spread and time of arrival of the tracer gas revealed how the gas actually travelled through the grid. This real-time information could then be compared with the virtual flow inside the model. A dry run of the test itself was done in Liander's "Gas Test Facility", a grid bypass in

Amsterdam where in a controlled and monitored environment gas flows up to 14.000m(n)3/h and a pressure up to 8bar can be achieved. During this dry-run phase intimate working knowledge of all the necessary equipment - and the tracer gas itself - was gained, to minimise the risk of any unforeseen problems during the upcoming field test.

The field test was designed in such a way that the gas grid itself does not have to be opened up and the live gas supply to customers remains uninterrupted. Existing valves, both under and above ground, where used to connect the equipment, or non-intrusive devices were used.The tracer gas test was a complete success and the Dynamic Grid Model was validated with it. The tracer technique itself is relatively simple and undisruptive to use and can be repeated indefinitely to fine-tune the model even further.

## Introduction

A grid operators main responsibility is to maintain a safe and reliable gas grid. In the past gas quality in the Netherlands was never an issue becausethe gas always originated from one single supplier. However the upcoming growth of bio methane insertion in the Netherlands, forces the grid operators, like Liander, to gain better understanding of the gas flows and the gas quality in its grid. When off spec gas is detected somewhere in the grid, it is imperative to be able to trace the origin in order to prevent further contamination of the grid.

## Dynamic grid model

Commissioned by Liander, the Dutch research institute TNO has developed a dynamic computer model of its gas grid. This model provides a predictive insight of how gas flows through the grid, making this model one of the building blocks towards the creation ofg a smart grid.

A combination of data from a variety of readily available measuring devices, including flowmeters, pressure and temperature sensors, as well as information from static modelling software, was used to build this dynamic model. As a base, grid information stored in the Geographical Information System (GIS) of the grid operator, was used to construct a virtual representation of the grid.

The simulations permit to use limited sensor readings to predict the flow inside a gas grid. Pressure, flow and mixture can be calculated at every location and at any moment in time. The calculation speed and accuracy of these calculations are critical requirements for this model.

The simulation methodology used in this model is based on simulation techniques which uses quantum field theory for describing elementary particles. The main requirement is an explicit mass balance. The methodology (also known as direct integration) automatically confines the amount of gas within the grid. By using the relations in an explicit manner, the methodology is also very fast in comparison to other simulation techniques. A necessary condition for this fast simulation methodology is an upfront inventory of the grid. All nodes and loops between insertion points and customers must be known.

# Validation project

To ensure the model is producing accurate results, a validation location was chosen, in which field measurements were taken and compared to the results of the model. To validate the dynamic model a tracer gas test was conceived and executed. At the beginning of the validation project a series of steps were defined.

1. Finding a suitable location for the model validation test
2. Determining the exact insertion and analysis points in the validation grid
3. Designing and building a tracer injection and analysis installation
4. Testing the tracer injection and analysis installation in Liandon’s Test Facility Gas
5. Installation and execution of the validation in the chosen grid
6. Running simulation using the boundary conditions measured during validation test
7. Analysing and comparing results gained from simulation and field validation test

## Model validation location

The first task during the project was to find a suitable location within the grid, to be used as a test location. This location was found in the city of Haarlem. A section of the 4 barg transportation grid in Haarlem fulfilled the conditions set at the beginning of the test, being not too large or too complicated, with only a limited amount of boundary crossing points and containing at least one loop.

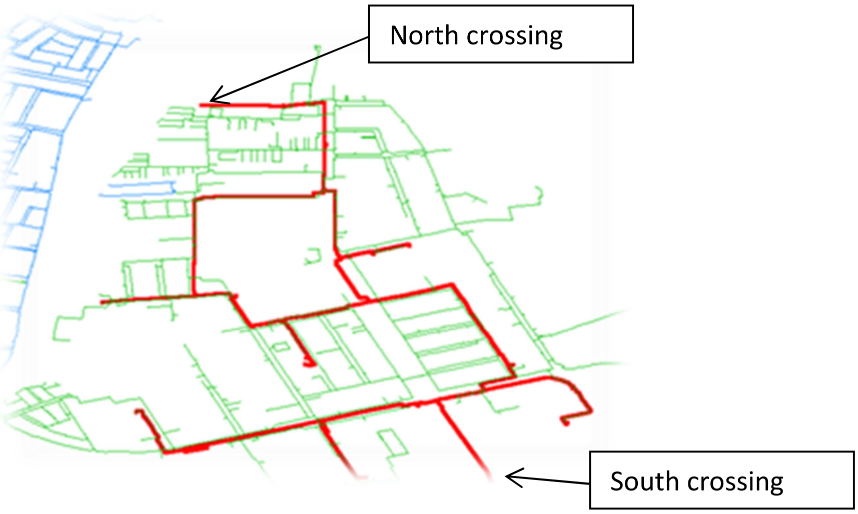


Figure 1 Schematic representation of the chosen grid with only two boundary points

The grid only crosses the chosen testing boundary at two locations, marked in figure 1 as north and south crossing. Inside the testing boundary lie several customers and gas reduction stations. Each of these points, as well as the boundary crossings will also have to be monitored. This is not an issue at the customers location due to the presence of gas meters used for billing purposes. The gas stations and gas lines at the crossings however are not monitored. Specific monitoring equipment had to be installed at these locations for the duration of this test.

## Injection and analysis points

After the test location was found, the exact points for the injection of the tracer gas and the location for measuring flow and for placing the tracer gas analysers needed to be determined. Some locations had to be chosen carefully due to the presence of contaminated grounds in certain parts of the validation grid. Soil samples were taken and analysed to confirm the chosen locations were clean.

## Designing and building a tracer injection and measuring system

To measure the gas flow within the grid a variety of sensors and instruments are necessary.

- Tracer gas injection and analysis equipment
- Flow measuring equipment

### Tracer gas injection and analysis equipment

The validation will take place using a tracer gas. After evaluating different ways of tracing, the choice was made for using $CO_2$ as the tracer gas. The main reasons for using $CO_2$ is the already natural occurrence of this component in Dutch natural gas and the fact that it is an inert gas. A rise of 1% on top of the already present $CO_2$-concentration of 2-3% is more than enough to detect using a precise $CO_2$ analyser.

For the injection of the $CO_2$ high pressure bottles were used. The bottles were connected to a buffer tank. Via a Bronkhorst High Tech In-Flow mass flow controller with a maximum capacity of 300 normal cube per hour the precise amount of $CO_2$ could be injected into the gas stream.

To measure the tracer gas concentration, a S-AGM plus (single Advanced Gasmitter Plus) from Sensor Europe GmbH was used. To control the flow to the analyser a Bronkhorst High Tech flow controller with a maximum of 10 litres per minute was used at the inlet side of the analyser.

### Flow measurements

To measure the flow within the grid different types of flow meters had to be used. At the boundary crossings the grid could not be disconnected, therefore the flow needed to be measured using clamp-on ultrasonic meters from General Electric, specially designed for gas flow measurements.

**Figure 2 Clamp-on ultrasonic flow meters (left photo: built onto a pipe line in the test facility ; right photo: built onto one of the pipe line in the field)**

The flows in the gas stations were measured using ST51 Thermal dispersion mass flow meters from FCI LLC. These meters could be mounted and inserted without the need of shutting down the gas supply through this station.

# Testing the tracer injection and analysis installation in Liandon’s Test Facility Gas

## Configuration

In Liandon’s Test Facility Gas a configuration was constructed to test the tracer injection and analyser installation. At the inlet side of the test setup the injection installation was connected to the main gas line.

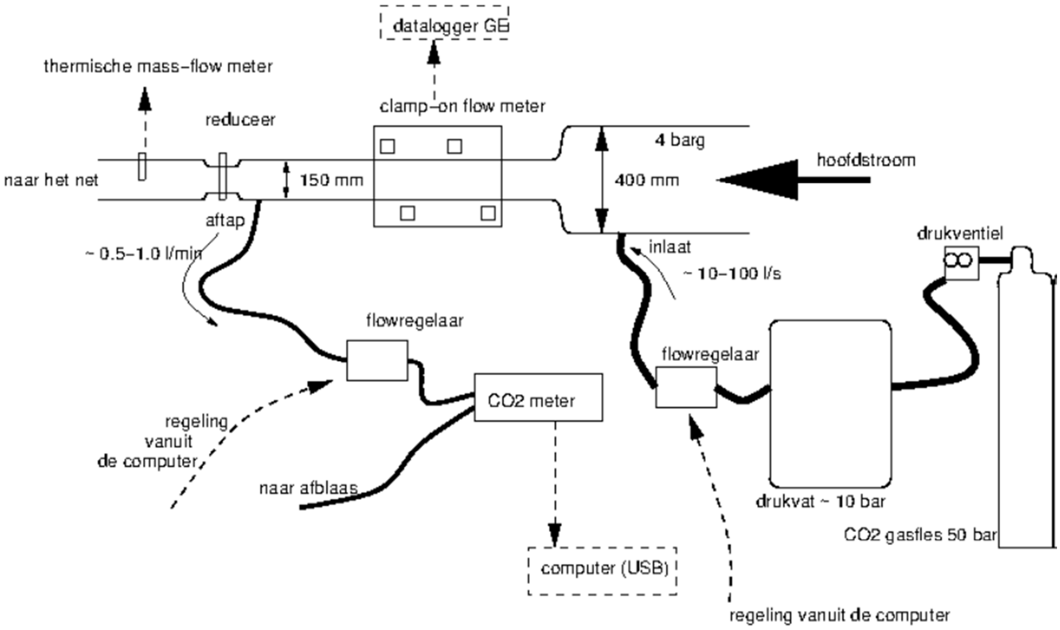


Figure 3 Schematic representation of the lab test setup, from right to left the tracer gas injector, the clamp-on flow meter and the tracer gas analyser

Behind the injection point the clamp-on flow meter was installed. The clamp-on is used to measure the total flow from which the necessary amount of tracer gas can be calculated. At the end of the setup the analyser was connected. All components are controlled from the lab’s control room.

The pressure inside the setup was raised to 4 barg and a fixed gas demand of 2000 normal cubes per hour was created at the end side. A number of dry runs were performed to gain a better understanding in the interaction and accuracy’s of the used components. This knowledge would later be used to minimise the risk of any unforeseen problems during the upcoming field test.

## Results

The need for a tracer gas buffer tank became evident during the first lab test sessions, where oscillations occurred when a direct connection between the $CO_2$ bottles and the mass flow controller was used. The introduction of a buffer resolved this problem and added the possibility to attach more than one bottle. The experiment showed that a single $CO_2$ bottle was able to deliver a capacity of 23 normal $m^3$/hr. During the field test higher tracer gas flows would be necessary meaning that at least four bottles would have to be connected simultaneously.

A concentration rise of 1% was measured by the analyser after injecting a calculated amount of trace gas, which proofed that the chosen configuration was working perfectly and that the field tests could commence.

# Installation and execution of the validation in the chosen grid

## Installation

At the beginning of the field test, all the required measurement equipment had to be installed. To successfully validate the simulation model two teams were simultaneously operating at different locations. At one location a team was responsible for measuring the flow using the clamp-on technology and to calculate and inject the necessary tracer amount.

Figure 4 Tracer gas injection point

At the second location another team was responsible for the measurement of the concentration of tracer gas within the gas flow. These sample locations are depicted in figure 5 as DS01 and DS02. By means of telephone the exact moment of injection was passed on to the second team. Using rough calculation results from the model an estimation was available of the duration between injection and detection of the tracer gas. This was helpful in determining if the analyser was working accordingly.

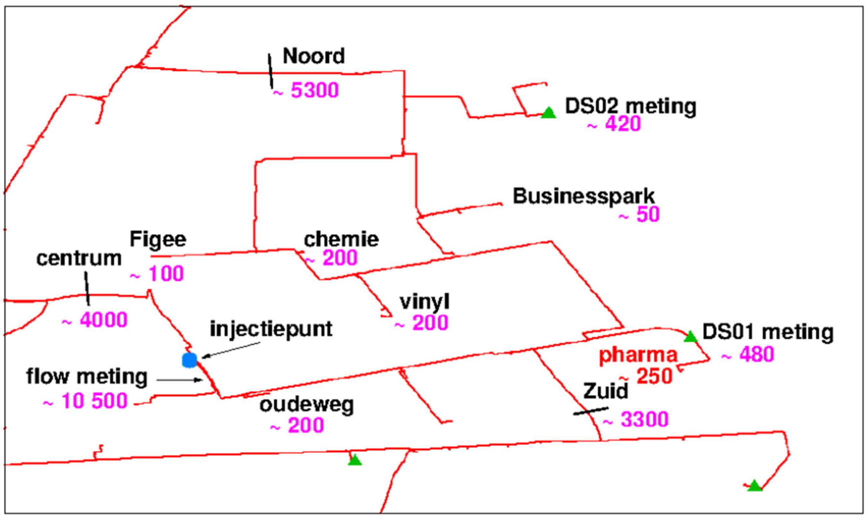
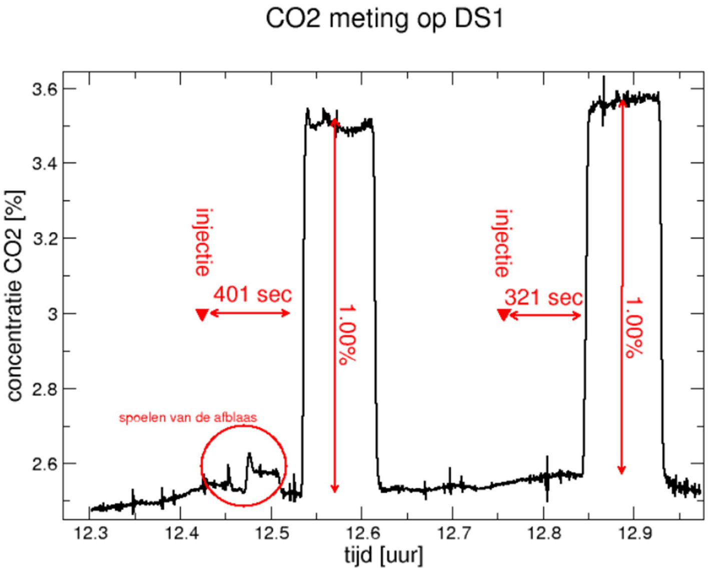


Figure 5 Schematic representation of the validation grid containing the flow values at each boundary point and the locations of injection and analysing of the tracer gas.

# Results

## First measuring location

The first two measurements were performed at gas station DS01, approximately 1,5 kilometres from the injection point. The first pulse arrived there after 6,5 minutes, the second try arrived after 5,5 minutes.



Figuur 6 Measured tracer concentration values at the first analysing location

The difference between the two values could later be explained due to a sudden increase in gas demand after the first measurement, leading to higher flows during the second measurement.

The results also showed that almost no spreading of the pulse had taken place during transportation. De block pulse that was injected six minutes earlier arrived at the analysing location almost unchanged. This was not expected. This surprising result was afterwards explained using the Taylor dispersion theory for turbulent flows. The theory describes a direct relationship between pressure loss and dispersion at high velocities. The lower the pressure drop, the less dispersion takes place. This was also the case at the test side where high velocities and almost no pressure loss was measured.

## Second measuring location

The third and fourth tracer gas measurement were made on gas station DS02. This station was located at approximately 2,5 kilometres from the point of injection. This meant that the expected time span between injection and detection would also be significantly longer than during the first two tests. Also due to the loop in this part of the grid, the tracer gas could flow via two seperate ways to the station. Measurements showed that the majority of the flow (97%) arrived via the main pipeline. The remaining 3% used the loop. Although no distinguishable concentration rise was expected through this loop, the results proofed otherwise.

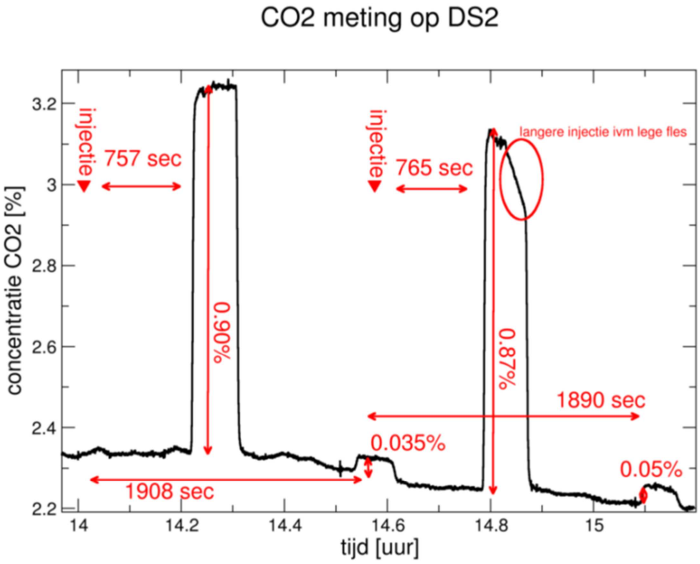


Figure 7 Measured concentration pulses of tracer gas at the second analysing location

The first pulse arrived at the gas station after 12 minutes, the second pulse took almost 32 minutes.

The second try gave almost the same results, differing less than 2% of the first one. The deviating form at the end of the second pulse from one emptytracer gas bottle. The remaining bottlescould not provide the necessary amount of tracer gas needed and the increase of 1% could not be maintained anymore.

## Conclusion

The tracer validation project was a success. The dynamic model, designed to predict flows, pressures and gas spreading in a 4 barg gas grid has been evaluated on the following points:

- The measured duration of a tracer gas pulse over a distance of several kilometres corresponds to the simulated value with a deviation far beneath 10%.
- Based on the measured duration values after the loop, the flow within that loop can be reconstructed with high accuracy.
- The measured tracer gas concentrations, being 1% of the total flow, are a near perfect match with the simulated values. This even counts for the concentrations after the loop, where the measured and calculated values were merely 0,04%.
- The spread of the pulse over time was limited, being a maximum of 20 seconds after five kilometres. This corresponds well with the calculated values.
- The flow within the grid moves like a clod. Almost no mixing occurs in the pipe lines. Mixing only takes place when two different flows merge.

This results in the fulfilment of the main objective of this project, being the validation of a dynamic model for predicting flows, pressures and gas spreading. Next to this main objective much insight was gained in the different aspects concerning the managing of a natural gas grid. The field measurements for example gave different results for the flows in this part of the grid than what was anticipated by the grid operator. This clearly shows the importance of such models for gaining a better understanding of gas flows within a grid.