Behavior of hydrogen leaks in the gas distribution network (DNV GL, report OGNL.184991)

The transition to a sustainable energy system is in full swing and is having a major impact on the networks of the Distribution Grid Operators (DSO's). Both the electricity and the gas network will be put to a different use. These networks supply most of the energy to the built environment, especially for heating households. Apart from the electrification of this heat demand, the DSO's still see a clear role for the gas distribution networks. The use of sustainably produced hydrogen offers a possible solution for decarbonizing household heating. One of the questions to be answered is how hydrogen can be safely used in the distribution networks. Netbeheer Nederland has set up a research programme to investigate this. An important aspect of this is to find out how hydrogen behaves compared to natural gas in the event of leaks in the gas distribution system. As part of the research programme, this study includes a desk study into the current level of knowledge on this aspect.

Risk analysis model

The approach of the study is based on a standard DNV GL risk analysis model for leaks in gas distribution networks. The H21 programme in the United Kingdom, among others, looks into the conditions under which hydrogen does not pose a greater risk than the current natural gas distribution system. As part of the English research programme, experiments are currently being conducted by DNV GL to support and validate the risk analysis model for hydrogen distribution networks. These results were not yet known at the time of writing this report.
The risk model distinguishes a number of steps that first describe the number of leaks and outflow of gas. The next stage is to examine how the released gas disperses in the open air, underground and in confined spaces. Consideration is given to whether an accumulated concentration of gas can be ignited and what the consequences of this are. A distinction is made between fires and explosions and their consequences. The insights regarding the differences between natural gas and hydrogen in the different steps are described successively. The comparison of the risk between natural gas and hydrogen in the distribution system depends on the probability of leakage, the accumulation of a hazardous concentration of gas, the probability of ignition and the consequences of this ignition. Each of these possibilities can be reduced by putting mitigating measures in place. Suggestions for mitigating measures are made for a number of situations.

The number of leaks and outflow

Most leaks in natural gas distribution networks occur in the connecting pipe, followed by the meter connection and the indoor piping; i.e. in and near the home. Most of these leaks are detected through gas odour being reported when third parties smell and recognize the odorized gas. Most leaks in the natural gas distribution system occur in distribution materials such as grey and ductile iron, asbestos cement and steel. With the exception of steel, these materials have not been used for some time and are being systematically removed from the gas distribution network. The

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materials used in the hydrogen distribution network are not expected to cause any further leaks. It is advisable to odorize the gas so that hydrogen leaks can be detected through people smelling the gas and reporting it.
The outflow volume of a leakage of hydrogen is greater than in the case of natural gas. With a small leak of around one litre per hour or less, the flow may be laminar and about 30% more hydrogen flows out based on volume. In the case of larger leaks, the flow becomes turbulent and releases 190% more hydrogen than natural gas based on volume. For low-calorific gas, the amount of energy released is about the same at the upper heating value and slightly lower at the lower heating value than for natural gas. No statistics have yet been compiled for the leakage size distribution and detection in hydrogen distribution networks. A register of leaks and their extent in future hydrogen distribution networks, similar to the current registration of natural gas leaks, could underpin these findings.

Distribution

The underground outflow of hydrogen through the soil can be accurately described with models, provided that the permeability of typical soil compositions is known. As well as soil composition, permeability is also influenced by weather conditions (rain, freezing weather). At equal pressures, hydrogen seems more likely to cause crater formation compared to natural gas. This can occur in particular at higher pressures in the gas distribution system (>200 mbar) and not at low pressures (<200 mbar). Crater formation would be favourable if the hydrogen is released into the atmosphere faster and does not diffuse underground into confined spaces. Additional experimental data is needed to produce validated models for the Dutch situation.
The lower density means that hydrogen will rise faster when blown off or leaked into the open air. Compared to natural gas, this does not lead to higher risks. Approximately the same amount of energy is released and initial calculations of the safety contours around a leak in a distribution pipe show that they are lower than for natural gas. The contour of the gas cloud is similar to that of natural gas.
Hydrogen spreads faster in confined spaces than natural gas. Experiments and simulations have shown that in the case of a leak in a non-ventilated space, hydrogen initially accumulates at the top of a confined space due to the difference in density, and then mixes to form a homogeneous blend. In situations where there is enough ventilation, the gas can escape to adjacent spaces. The concentration of hydrogen therefore remains low and will be smelt sooner, provided it is odorized. Natural gas exhibits a similar behaviour, but because the density difference with air is much smaller the diffusion will be slower. Hydrogen will lead to higher concentrations than natural gas at the same leakage rate.

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Ignition

The ignition energy of a flammable mixture of hydrogen and air depends on its concentration. In a stoichiometric mixture, the minimum ignition energy of hydrogen in air is much lower than for natural gas, and ignition sources with weak static discharge are therefore generally sufficient to ignite the mixture. However, mixtures of air and hydrogen in low concentrations, up to about 8 - 10 vol%, have a lower risk of ignition than natural gas. Sparks caused by electrical equipment or switches should theoretically be sufficient to ignite these low concentrations as well. However, the literature does not give a clear view of which sources do or do not lead to ignition: although tested with ignition sources that have sufficient energy for ignition, they do not always appear to ignite a flammable mixture.

Consequences: fire or explosion

To determine the consequences of ignition, a distinction is made between burning hydrogen by means of a flame or by means of deflagration or detonation. In an open space and at low concentrations (<10 vol% hydrogen in air) a fire will break out. No overpressures were found in the experiments at concentrations below 10% hydrogen. Explosions may occur in confined spaces or at higher concentrations.

Hydrogen fires have the same or lower heat radiation at the same capacity as natural gas. Equal heat radiation occurs in fires in which dust/soil is also burnt. The heat radiation for free flames of hydrogen, which are also less visible, will be lower than for natural gas. At equal pressures, the effect of the flame will be less than that of natural gas with a lower energy outflow. This is confirmed by measurements.

Experiments show that in the case of hydrogen the overpressure increases on ignition from concentrations above 10 vol%. With a stoichiometric mixture (around 30 vol%) overpressures can occur that exceed 100 mbar. The stoichiometric mixture for natural gas is 9.5 vol%. Overpressures of up to 6 bars have been measured during natural gas explosions. Walls collapse at overpressures of 140 mbar, and at 420 mbar houses are largely destroyed. Due to the higher reactivity of hydrogen, it is expected that a stoichiometric mixture of hydrogen is more likely to cause a detonation. Further study is needed to confirm this and to further establish the impact compared to natural gas.

Risk comparison and recommendations

The comparison between the risks of natural gas and hydrogen depends on the situation. In summary, the risks of natural gas and hydrogen are expected to be comparable in the case of free flow in the open air. In the case of underground leaks, the chance of an unsafe situation is expected to be lower if a permeable top layer is present, but the likelihood of this increases if the top layer is impermeable (especially during freezing weather), due to hydrogen migrating to buildings.

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If there is a leak in a home or hydrogen enters the home via migration through the soil, the risk depends on the concentration that can be built up: if the concentration of hydrogen remains below 10 vol%, there is a lower probability of damage because the likelihood of ignition is lower than with natural gas and because no explosion is likely to occur if ignition takes place.
For concentrations above 10 vol%, hydrogen presents a greater risk of damage because the chance of deflagration is higher than with natural gas and the pressure builds up much faster. These concentrations can be exceeded in the case of large leaks (from 100 to 300 l/min), especially if the leak occurs in a confined space (meter cupboard, crawl space, etc.). A number of suggestions for mitigating measures to reduce these risks are given, such as the use of LEL sensors, odorization or the use of automatic valves.
An agreement on the measures to be taken will have to be reached to ultimately achieve an acceptable risk for the use of hydrogen in distribution networks. It is important to reduce the uncertainty in the probabilities and consequences of the various aspects as much as possible. This means that statistics and practical experience need to be accumulated for the use of hydrogen in the built environment. Within the H21 project, various experiments are currently being carried out that will provide further insights. These include measurements of the build-up of hydrogen concentration in houses, diffusion through the soil and ignition from various sources. It is advisable to translate the results of these experiments to the Dutch situation, and where necessary to supplement them with necessary experiments.

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