WRITE-UP OF WEBINAR FOR IPLOCA

CONSIDERATIONS ON HYDROGEN FOR AN ONGOING GAS PIPELINE PROJECT IN EUROPE

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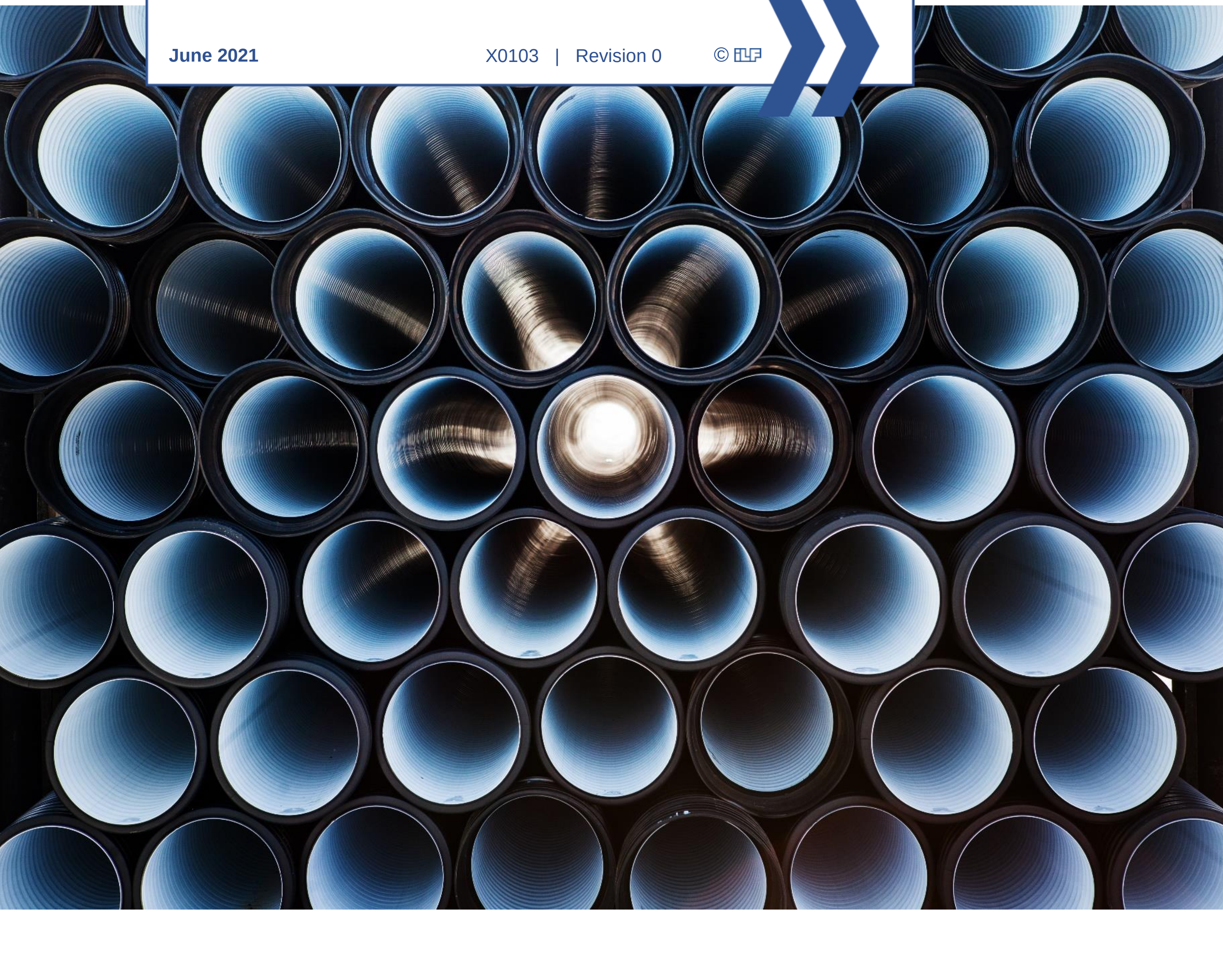

ABSTRACT

ILF is currently involved in the design of several gas pipelines in Europe. The investment is considered for a long period, i.e. >50 years. The ongoing developments in Europe related to generation of Hydrogen from excess wind and solar energy and its planned admixture and transport in the existing pipeline grid will impact as well these Pipeline networks. In this respect ILF Consulting Engineers had been asked to conduct an assessment to what degree such modifications of the transported medium is having influence to the already designed pipeline system. The study had been assessing several scenarios with different concentrations of Hydrogen and had been investigating in detail:

- Impact on existing Permit Documentation
- Impact related to the overall Pipeline Network, i.e. considering the existing pipeline infrastructure connected to it
- Review of existing technical project documentation related to suitability of admixture of hydrogen.
- Assessment on Impact of Costs and Time for the project.

In a second, further assessment, it was considered that Natural Gas should be exchanged to 100% to hydrogen. For this approach a dedicated new “Basis of Design” for the project had been developed, now for pure hydrogen. This “Basis of Design” covers all relevant aspects of the design of a gas Pipeline, i.e. flow scenarios, venting and first fill considerations, material aspects, aspects related to station design, hazardous areas and many more. Then a “Gap Analysis” between this new “Basis of Design” for a Hydrogen Pipeline and the existing Project documentation had been conducted and conclusions resulting here-from had been drawn. It was concluded, which technical modification would have to be done in the future, if the pipeline, currently designed for natural gas, shall be changed into a 100% H2 compatible pipeline.

1 INTRODUCTION

One of ILF's clients has recently been completing the design and engineering aspects of a natural gas pipeline in Central Europe and now plans to commence with procurement activities of the line pipe and main equipment. This specific project consisted of a gas pipeline of approximately 100 km length, pipeline diameter 40 Inch, Pig launcher and Pig receiver station, several valve stations. The compressor station, which generates the pressure for the transport of the gas is located a certain distance upstream and has not been directly included in the project. According to the project requirements, the medium to be transported shall be natural gas with a standard composition.

The investment into a pipeline project is considered for a long period, i.e. >50 years. The developments in Europe regarding the generation of hydrogen from the surplus of wind and solar energy and its planned admixture and transport in the existing pipeline grid have only started in the last few years. In this respect, ILF had been asked by its client to conduct an assessment to what degree the admixture of hydrogen into natural gas would have influence towards the designed pipeline system. This study had been assessing the scenarios with 2 %, 5 % and 10 % content of hydrogen in the natural gas. It has been studied whether, and to what extent, the current project documentation may need to be modified, in order to be ready for receipt of blended gas. The impact related to the overall pipeline network had been assessed, i.e. considering the existing pipeline infrastructure connected to it. For all considerations, it was of paramount importance that the ongoing permitting process with the authorities is not disturbed and construction permits already provided remain valid.

In a second, further assessment, it was considered that natural gas should be exchanged to 100 % hydrogen. For this approach, a dedicated new "Basis of Design" had been developed for the project, now for pure hydrogen. This "Basis of Design" covers all relevant aspects of the design of a hydrogen pipeline, i.e. flow scenarios, venting and first fill considerations, material aspects, aspects related to station design, hazardous areas and many more.

A subsequent "Gap Analysis" between this new "Basis of Design" for a hydrogen pipeline and the existing project documentation had been conducted and resulting conclusions drawn. It was further concluded, which technical modifications would have to be done in future, if the pipeline currently designed for natural gas shall be converted into a 100 % H2 compatible pipeline.

2 ASSESSMENT ON 2 %, 5 % AND 10 % OF HYDROGEN ADMIXTURE

This chapter summarizes the assessment conducted on admixture of 2 %, 5 % and 10 % of hydrogen into the natural gas. It was investigated to what extent the blended gas is meeting the formal requirements of the legislation related to natural gas. It was then assessed, whether and to what extent an impact to the permitting situation may be expected and which may be the impact to the consumers and the overall gas distribution network. Recommendations are made in respect to modifications of the existing project documentation.

2.1 Considerations on the Definition of Natural Gas, Permitting Aspects and Overall Gas Distribution Network

2.1.1 Considerations on the Definition of Natural Gas

The first step was to determine the changes in the composition of gas for the different scenarios of adding 2 %, 5 % and 10 % hydrogen, and to verify whether the new compositions are compliant with the governing legislation.

The governing legislation defines requirements for Higher Heating Value, Wobbe Index and Relative Density for the natural gas. The requirements are in principle such that the gas properties need be in the red marked area of the below sketch.

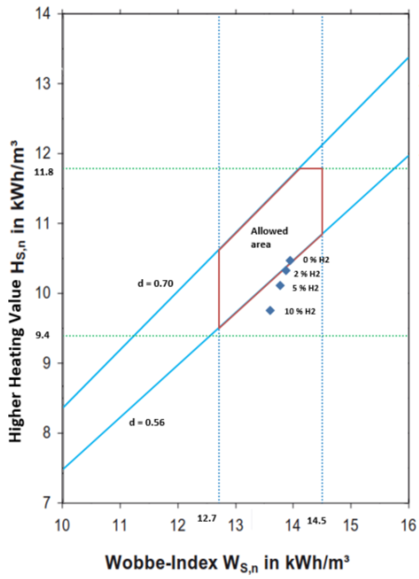

Figure 1: Relevant parameters for definition of natural gas

The admixed hydrogen slightly reduces the Wobbe Index, as well as the higher heating value of gas. As shown in the above sketch apparently the gas properties without hydrogen admixture is fulfilling these criteria, whilst when admixing hydrogen this is no longer the case. The study showed that in this particular case, the gas with added hydrogen would not be in compliance with the governing legislation.

2.1.2 Considerations on Impact on Permit Documentation

As mentioned, the considered pipeline system had been designed in the last couple of years, where natural gas as medium has been considered. The permitting process with the authorities was ongoing at the time study was performed. In order not to interfere with the project time schedule it was required not to disturb the permitting process.

To assess a potential impact on the permitting process, the formal definition of the gas as it is referred to in the permits and permit documentation and been studied. Further the influence on the validity of the already completed Environmental Impact Assessment (EIA) had been assessed and the operator’s formal license for gas transport had been considered.

The following conclusions had been drawn from the investigations: The governing legislation applicable for this particular project does not mention any allowed amount of hydrogen in the definition of the natural gas as medium. It may be concluded that at this time neither 2 % nor 5 % nor 10 % of hydrogen in natural gas is actually formally allowed by definition. On the other hand, the admixture of hydrogen to natural gas is not explicitly forbidden in the considered country's legislation. This uncertainty may cause a risk for the project and result in problems for all parts of a permitting process. It is apparent that the legal issue of hydrogen admixture requires further attention, where this aspect should be addressed preferably by European regulations.

2.1.3 Considerations Related to the Overall Pipeline Network

Along the route, the natural gas from the pipeline project considered shall be delivered to other natural gas pipeline systems and to local/regional distribution systems, to local consumers and, among others, to underground gas storage facilities. In this respect, it is relevant to assess, to what extent these downstream consumers are able to cope with the admixture of hydrogen.

For this particular project the following aspects and concerns have been identified:

- The natural gas distribution networks have been built over decades and therefore are made from lots of different steel grades and partially as well from polyethylene (PE) pipes. Several pilot projects are currently run in the EU, to prove that gas appliances in accordance with EN 437 tested for natural gas (operational performance and leak testing) were also safe on hydrogen admixtures containing up to 20 % hydrogen, see e.g. [1, 2]. From these studies it had been concluded that permeability of hydrogen through the materials of the natural gas distribution networks is not considered as significant as long as admixture of hydrogen is limited to below 10 %.
- In the area of the considered pipeline project there are several underground gas storage facilities (UGS), which can be supplied directly with the pipeline gas. Usually UGS are operating at elevated pressures when compared to pipeline operation pressure. As a consequence, the partial pressures resulting from admixture of hydrogen is as well higher, leading to an increased likelihood for hydrogen embrittlement. In the case of hydrogen blending with natural gas, the UGS facilities have to be analysed on a case-by-case basis for different hydrogen blends. Again, there are several ongoing research projects, which are investigating the effect of storing hydrogen-natural-gas mixtures in UGSs on the integrity and performance of reservoirs and UGS facilities, see e.g. [3]. It is expected that the results of those research projects shall be the base for a revision of the EN 1918 Underground Gas Storage Standard.
- Within the project area there are gas turbine and gas engine installations available, partially for power generation, partially as compressors for the pipeline system. Generally gas turbine and gas engine are consumers with specified and often very stringent limits on natural gas as a fuel. Typically, gas turbine combustion systems are specified and tuned for local compositions of natural gas. Many current fuel specifications for many gas turbines place a limit on hydrogen volume fraction in natural gas below 5 %, but some turbines in operation may have hydrogen limitation at 1 %. The behaviour of the operating characteristics of gas turbines with admixture of hydrogen has to be investigated and tested from consumer to consumer.

- In the area of the project considered, there are several CNG (Compressed Natural Gas) filling stations for cars. Derived from the total number of CNG cars in the country, it can be estimated that in the area considered, there are several thousands of CNG cars. Most of those cars have CNG tanks made of high-strength steel, and CNG with hydrogen concentration larger than 2% may not be filled. According to ECE Regulation No. 110 the hydrogen content shall be limited to 2% by volume when CNG car cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa.

Due to the fact that there are industrial gas users connected to the network and these gas users have limitations as described above, a general statement that hydrogen concentration of 2 %, 5 % or 10 % may already be used at this point in time, cannot be provided.

2.2 Review of Pipeline System Properties and Project Materials

The technical documentation originally developed and issued for the pipeline project for natural gas had been reviewed to identify the possible changes and improvements required for hydrogen admixtures up to 10%.

The considerations performed refer first to pipeline system properties and then to components and materials.

2.2.1 Pipeline System Considerations

The following technical impacts are considered and evaluated in the study, with the most relevant aspects summarized here. The identified impacts on the pipeline system itself are as follows:

<u>Transport Capacities</u>
The admixture of 10 % hydrogen results in a 5-6 % decrease of the pipeline transport capacity. However, as the full transport capacities of natural gas pipelines are fully utilized only on a few days per year, the operational margin allows an increase in the transported gas volume.

<u>Hazardous Areas</u>
When plotting the Maximum Experimental Safety Gap (MESG) against the Hydrogen Content, it may be derived that Natural gas and admixtures with up to 25% content of hydrogen belong to the same explosion group (IIA), refer Fig below.

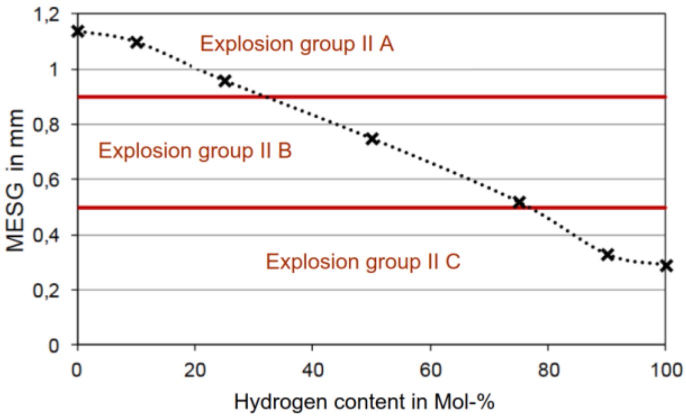

Figure 2: Impact from Hydrogen content on Explosion Group

Consequently, it is not required to change the design of equipment suitable for installation into potentially hazardous areas, for the mixture rates of 2 %, 5 % or 10 % hydrogen.

The hazardous area classification in the considered project have been based, among other parameters, on Lower Explosion Limit (LEL) of natural gas. For 2%, 5% and 10% hydrogen content in natural gas the changes in LEL are insignificant, and this would only lead to slightly higher cones for the vent sources. An update of the project documentation was not considered as relevant.

Vibration Criteria in Main Valve Bypass Piping

Further, the acoustic and flow-induced vibrations for natural gas and the admixture of hydrogen up to 10 % have been assessed. For these investigations the admissible limits on acoustic and flow-induced vibration levels have been defined and the corresponding maximum mass flow rates and respective opening positions for the installed control valves have been determined then. These investigations showed that the allowable mass flows are lower when hydrogen is admixed, although the lower density of the gas more than compensates this effect. As a consequence, the control valve has to be closed a little more. The resulting velocities are higher and thus the time required for filling the adjacent pipeline section is reduced.

However, the changes are in the range of 5 % and thus the influence can be neglected for the admixture of up to 10 % hydrogen. There was no need to update the technical design, thus there is no impact on the permit process.

Emergency Venting

The emergency venting has been assessed with a similar approach: The mass flowrate is considered as being the relevant parameter for pipeline blowdown/venting and in the case of hydrogen admixtures up to 10 % the changes in mass flowrate are 5 % and below.

On the other hand, the density of the hydrogen admixtures up to 10 % is lower than for natural gas and blowdown time shall be reduced by approximately 5 %.

The effect of hydrogen admixtures up to 10% on blowdown/venting comparing to plain natural gas is considered as negligible. There is no need to update the technical design, thus there is no impact on currently running permit process.

Fire Safety

Based on the assessment in the study it is concluded that the use of hydrogen admixtures up to 10 %, under well regulated conditions, shall not increase the risk of fire in comparison to those with unblended natural gas.

2.2.2 Considerations on Components and Materials

The impacts on mechanical equipment and material technical specifications and datasheets had been assessed in detail. This may be summarized as follows:

An assessment was conducted regarding the materials to be used for the project. In principle, in the case of hydrogen admixture, it is recommended to purchase steel material with confirmed hydrogen compatibility. According to IGC Doc 121/14, lower strength materials such as API 5L X52 and lower grades, are suitable for hydrogen service. Higher grades, such as API 5L X70, are not recommended as per IGC Doc 121/14, as it is assumed, that higher strength steels are more susceptible to hydrogen embrittlement and cracking.

The recommendations of the latest issue of ASME B31.12 are similar to those above, with the exception that higher strength steels (up to API 5L X80) are allowed, but with large penalties imposed on material grades X60 and higher, resulting in higher wall thicknesses.

It is important to note that both the requirements of IGC Doc 121/14 and ASME B31.12 are applicable for 100 % hydrogen pipelines. These requirements are very conservative for pipelines transporting the hydrogen admixtures with up to only 10% hydrogen. For the specific project considered with 10% hydrogen admixture, the partial pressure of hydrogen is around 7 barg. During the earlier design phase of the project, it was decided that X52NE and X70ME materials shall be used for station piping and pipeline, respectively. In case the current recommendations of IGC Doc 121/14 and ASME B31.12 would be followed, this would result in significant increases of the pipeline wall thickness (approx. 30 %) for the X70ME pipes. For several reasons these changes where however not recommended. On the one hand side the partial pressures are considered low. Then, there is as well a discussion that the current recommendations from ASME B31.12 may be modified in the next revision of the document, and that then no change would be required for the pipeline material or wall thickness in order to accommodate up to 10% hydrogen admixture. Last not least, the operator later-on may always have the possibility to reduce the operating pressure of the pipeline, should this indeed be required by future legislation.

In respect to equipment (valves, scraper traps, pig signallers) and material (pipes, fittings, flanges, induction bends, etc.) specified for the project the following was however concluded. For reasons mainly related to the procurement process and warranty from vendors, it was recommended to add minor modifications to the existing documentation, to be in line with ASME B31.12, such as:

- For all steel materials it is recommendable to limit the Carbon Equivalent Value to maximum 0.43 and sulphur content to maximum 0.025 %.
- For the line pipes it is recommendable to control the hardness maximum to 22 HRC.
- For this specific project the client initially required to use gas hydraulic actuators. For hydrogen admixtures with higher content (5 % and 10 %) it is recommended to change the type of valve actuator from gas-hydraulic to electro-hydraulic.
- It is recommended to use helium for the valve pressure and tightness tests.

As a conclusion, from the technical point of view, the new pipeline system, when observed independently of its surrounding, can be used for the transport of hydrogen admixtures 2 %, 5 % and 10 %.

However, as some limiting areas downstream of the gas delivery points have been identified, it is recommended to limit the concentration of hydrogen in the natural gas grid to 2 %, as long as CNG car filling stations and sensitive users (such as gas turbines and gas engines) with low hydrogen tolerances are connected to the natural gas grid. The concentration of hydrogen in transported gas may be increased to 5 % or even to 10 % of hydrogen content in the future, when CNG car tank types, and sensitive users such as gas turbines or gas engines, are upgraded/modified or replaced by new types which are able to cope with higher hydrogen concentrations.

3 CONSIDERATIONS FOR A 100 % HYDROGEN PIPELINE

For the considerations of a 100 % hydrogen pipeline the following approach was selected: A completely new "Basis of Design" was developed while keeping length and diameter of the pipeline. This new "Basis of Design" included capacity calculations and the comparison of the transport capacity for a case with natural gas and has focused on materials, safety issues and components to be used.

In a second step a "Gap Analysis" between this new "Basis of Design" for a hydrogen pipeline and the existing project documentation was conducted. Finally, an assessment was conducted on recommended technical modifications, if ILF's client indeed plans to convert the pipeline, currently designed for natural gas, into a 100 % H2 compatible pipeline.

The "Gap Analysis" showed the following main differences:

- The explosion group for a hydrogen pipeline (IIC) is higher than for a natural gas pipeline (IIA). This will affect all electrical equipment and instrumentation installed in hazardous areas.
- The venting of hydrogen shall be collected and routed to a single stationary or mobile venting point at the safe location within the station fence. This may have an impact on the plot size of the block valve stations. The reason for the selection of designated venting stacks is easy inflammation of hydrogen compared to natural gas.
- The number of flanged connections shall be reduced as far as practically possible to avoid the leak of hydrogen.
- The welding procedures for the hydrogen pipeline may need to be adapted, in particular in respect the pre- and post-weld treatments.
- In order to reduce the risk on hydrogen embrittlement it may be advisable to reduce the number of welds as far as possible. In this respect, and as well as due to further technical considerations, longitudinal welded pipes may be preferred, compared to helical seam welded pipes.
- Electro-hydraulic and electric valve actuators shall be used instead of gas-hydraulic actuators in order to limit leakage of hydrogen.
- The application of Material Performance Factor in wall thickness calculation for hydrogen pipeline and station piping will result in higher wall thicknesses compared to natural gas pipeline. Alternatively, the Maximum Operating Pressure may have to be reduced.
- The leak testing of valves with helium is required for hydrogen pipeline valves.
- A fire and gas detection is required at block valve stations of hydrogen pipelines, due to the hydrogen characteristics.
- The power required for the transport of the same quantity of energy with hydrogen is more than three-times higher compared to natural gas. This will have an impact on operability (OPEX).
- The transport capacity of hydrogen pipeline in terms of energy is smaller by the factor of 1.2 compared to natural gas pipeline.

- The cost and complexity of compressors and compressor stations for hydrogen pipeline is significantly higher compared to natural gas pipelines.

Last not least for a possible conversion of a natural gas pipeline to a 100 % hydrogen pipeline, the following conclusions have been drawn:

- A thorough integrity assessment of the existing pipeline is required. This includes extensive intelligent pigging and related evaluations on the current status of this pipeline.
- The electrical equipment and instrumentation for Explosion Group IIA shall be replaced with electrical equipment and instrumentation for Explosion Group IIC.
- Fire and gas detection shall be provided at block valve stations.
- Direct gas valve actuators shall be replaced by electro-hydraulic or electric valve actuators.
- The existing flanged connections shall be carefully assessed and replaced by welded connections where possible.
- All local vents shall be collected and piped to venting stacks. It may be necessary to acquire appropriate land for the location of such venting stacks.
- Appropriate operating permits must be obtained from the relevant authorities.
- The operation and maintenance personnel shall be trained in in the operation of specifics of hydrogen.

In summary, a conversion of an existing natural gas pipeline into a hydrogen pipeline may in principle be possible, although technical modifications must be considered, see listing above. In case of a conversion, the maximum operating pressure has to be recalculated according to the applicable standards and regulations at that point in time. The impact on costs for such a conversion of the pipeline itself may still be considered as “moderate”. Regarding the overall hydraulic scheme the following is noted: In order to transport the same energy in the pipelines, significant more compressor power is required for the hydrogen case. Dedicated hydraulic analysis’ and further detailed studies need to be conducted to decide on location, type and size of the compressor stations. The conversion of compressor stations and/or the additional compressor stations required for hydrogen will in any case be a “significant” cost impact.

[1] HyDeploy: The UK's First Hydrogen Blending Deployment Project, Clean Energy 2019;
[2] Avacon Pilot Project in Shopsdorf: Hydrogen Levels in German Gas Distribution System Rised to 20 % for the First Time, E.ON 2019
[3] The Effects of Hydrogen Injection in Natural Gas Network for the Dutch Underground Storages, Netherlands Enterprise Agency, 2017.

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