The NATURALHY project: first step in assessing the potential of the existing natural gas network for hydrogen delivery

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1. ABSTRACT

Currently major research effort is focused on the use of hydrogen as an energy vector both in Europe and the US. An obvious pragmatic solution for transporting hydrogen, which will be necessary to make the European hydrogen economy feasible, could be to transport a mixture of natural gas and hydrogen in the actual existing natural gas pipe network.
Within the European project NATURALHY, 39 European partners have combined their efforts to assess the effects of the presence of hydrogen on the existing gas network. Key issues are the durability of pipeline material, integrity management, safety aspects, life-cycle and socio-economic assessment and end-use.

The NATURALHY concept of using the existing natural gas grid for the transport of a mixture of hydrogen and natural gas supports basically two separate strategies. One is the "greening of gas" (if hydrogen is produced without CO2 emission), by directly feeding the mixture into end use appliances. The other is the "transport of hydrogen", where pure or nearly pure hydrogen is separated from the mixture by newly developed cost-effective membranes for the use in a variety of hydrogen applications, helping to accelerate the transition towards the hydrogen economy.

All results of the NATURALHY work packages will be integrated in the Decision Support Tool, a software tool developed with in the NATURALHY project that can be used by the pipeline operator to decide whether or not to inject a certain level of hydrogen into an existing gas grid.

The paper gives an overview of the current results obtained in the project. More details can be found at the project website: www.naturalhy.net

C O N T E N T S

2. BODY OF PAPER

2.1. Introduction

The transition towards the hydrogen economy will be lengthy (decades), costly and requires a significant R&D effort. Depending on the hydrogen penetration scenario, the cost of a new hydrogen pipeline infrastructure in Europe may amount to hundreds or even thousands of billions of Euros. It is therefore a practical strategy to assess to what extent the existing assets including the natural gas infrastructure might be used for hydrogen delivery during the transition to the hydrogen economy.

As the physical and chemical properties of hydrogen differ significantly from natural gas, it is not possible to simply exchange natural gas by pure hydrogen in the existing natural gas network. However, the natural gas system offers a unique opportunity to introduce hydrogen gradually to consumers, supposing that a safe and reliable operation is possible, by supplying a natural gas / hydrogen mixture.

The knowledge gained in this project is not only valuable for assessing the potential of the existing natural gas system for the delivery of pure hydrogen; it is also relevant for the option "greening of gas", which means the reduction of CO2 emissions by replacing part of the natural gas either by hydrogen (produced without CO2 emissions) or biogas that contains a fraction of hydrogen.

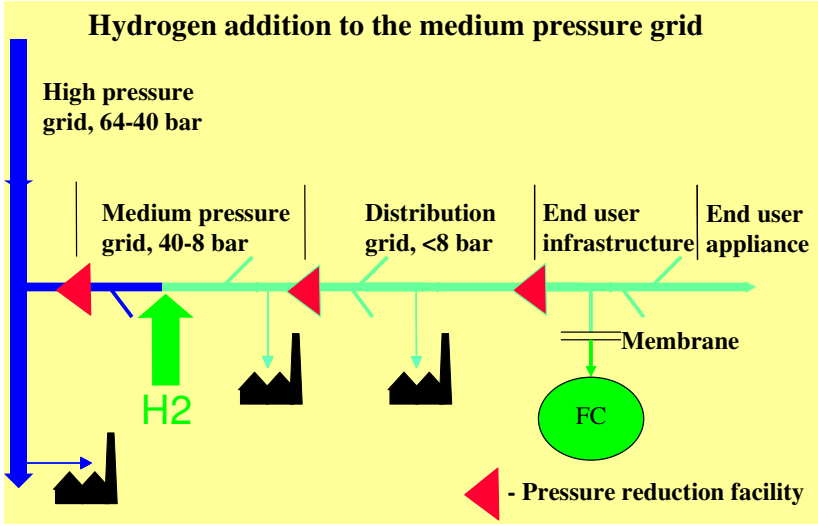

Figure 1 Diagram showing NATURALHY concept

Adding hydrogen to natural gas will change the properties of the gas, and may affect, for instance:

- the combustion properties;
- the durability aspects of the pipeline systems (it is known that hydrogen can diffuse into steel and polymer pipes and change the material properties);

- the energy capacity of a pipeline (the caloric value of natural gas is about 3 times the value for hydrogen, but on the other hand hydrogen flows through a pipe with less resistance);
- gaseous and energy losses due to permeation of hydrogen through pipes and small leaks.

The impact on combustion properties is not only relevant for the performance of end user appliances but also for the safety risks related to the transmission, distribution and use of the gas. Within the NATURALHY project, gas accumulation, fire and explosion experiments with hydrogen/methane mixtures are being performed as current mathematical models are not capable of accurately predicting these hazards with hydrogen / natural gas mixtures.

Figure 2 High pressure jet fire conducted as part of Naturalhy project

The aim of the fire and explosion experiments is to assess any change in risk to the public caused by adding hydrogen to natural gas. In particular, the tests are assessing any change in the consequences of a gas escape in terms of fire or explosion hazard.

The results from other work packages, determining to what extent the durability and integrity of pipeline steels is affected by hydrogen, will be used for the calculation of the probability of failure and ultimately for the assessment of risk to the public in the safety work package.

Durability of pipeline materials is an important issue concerning the technical/economic lifetime of the transmission system and it is also a key aspect regarding safety risks. Within the NATURALHY project, the material degradation due to hydrogen induced ageing of pipeline materials as used for existing pipelines is being investigated.

Furthermore it is of eminent importance to guarantee and maintain a required level of integrity within the pipeline system. It has to be determined whether the current condition

monitoring techniques for natural gas pipelines are sufficiently adequate to detect defects, which become more critical in a hydrogen environment, as it is essential to avoid failure between two inspection intervals. Thus it might be necessary to improve the tool sensitivity and/or to shorten inspection intervals in order to maintain an acceptable integrity level in the case where hydrogen is added to natural gas. As mentioned before the results, of this work package will also be used for the risk assessment in the safety work package.

Figure 3 New pipeline sections ready for Construction

The other main subject addressed in the NATURALHY project concerns the separation of hydrogen from hydrogen/natural gas mixtures and the effect of the presence of hydrogen on the use of the mixture by end-users. Various separation scenarios are therefore evaluated within the NATURALHY project. The NATURALHY project focuses particularly on the development of low-cost, high efficient membranes, which could be used for the subtraction of pure hydrogen from the medium transmission grid (operated below 40 bars) to be used in fuel cells. The changes in gas composition downstream the separation will have a major effect on the safe and reliable operation of appliances. Hence, the performance and efficiency of typical domestic appliances with different levels of hydrogen is being assessed.

Figure 4 Boiler at test site in DGC laboratory

Life cycle analysis and socio-economic assessment of the injection of hydrogen into the natural gas grid is also a subject for study in a work package of the NATURALHY project.

All results of the NATURALHY work packages will be integrated in the Decision Support Tool, a software tool developed with in the NATURALHY project that can be used by the pipeline operator to decide whether or not to inject a certain level of hydrogen into an existing gas grid.

2.2. Current results of the project

To date, the NATURALHY project has been underway for four years. A summary of the most important results achieved so far is being described in the following sections:

- Although it is not yet possible to say, conclusively, what precise level of hydrogen may be safely added to existing natural gas networks, provisional indications can be provided. Results from fracture toughness tests at 100% hydrogen indicate that there is no significant effect on embrittelment for the pipeline material tested in the NATURALHY project. However, the results from fatigue tests show that the maximum allowable percentage of hydrogen for the modern (low carbon) steels might be limited to values below 50%. This has been an unexpected result as it was initially thought that older steel pipes might be the limiting factor. Hence, more tests are planned with modern steel pipes in the coming period of the NATURALHY project, at lower hydrogen levels to determine the maximum allowable level of hydrogen for this type of steel. However, in the same way as a chain is only as strong as its weakest link, the maximum level of hydrogen will depend on a careful analysis of impacts across the whole gas chain.
- The modern pre-mixed domestic boilers tested in the NATURALHY project can tolerate mixtures containing more than 70% hydrogen in natural gas, apparently with a

slightly lower or constant thermal efficiency. These are potentially very important results, obtained both in laboratory tests and in year-long field trials. In practice the market consists of a mixture of new and old, premixed and non-premixed appliances forcing the distribution company to maintain the gas quality for distribution between a well defined upper and lower limit. As a consequence the maximum allowable level of hydrogen present in the distributed natural gas depends on whether the natural gas is currently distributed near the upper or lower quality limit. Moreover, there is a large variation in these quality limits used between European Union Member States and, consequently, this would lead to a significant variation in maximum allowable hydrogen by location. Taking these factors into account, the maximum allowed percentage of hydrogen in natural gas could be restricted to 20% if no additional or mitigation measures are taken.

- The preliminary end use results as mentioned above indicate that natural gas/hydrogen mixtures could be used in the existing end use market and that the "greening of gas" objective for the NATURALHY project is achievable.
- Data on the safety of natural gas/hydrogen mixtures in confined and unconfined locations have been obtained from large scale fire and explosion tests at the unique Spadeadam facility. These tests determine empirical factors that can be applied to the predictions of existing natural gas models or hydrogen models to account for the differences in the consequences of release resulting from the presence of hydrogen. Current preliminary results indicate that mixtures of up to 20% hydrogen in natural gas will bring no significant increase in explosion severity. This work is of paramount importance in assuring both gas operators and health and safety regulators that the addition of hydrogen to natural gas will not compromise safety. The results of the fire experiments that will become available in the coming final (extended) period of the project are also very important for a more accurate assessment of the effect of an incident occurring (a failure of a pipeline) and the way the presence of hydrogen will affect this. Only in the final period of the project, when both the effect and the likelihood of an incident are established, will an accurate assessment of risk be possible. This is one of the crucial outcomes of the NATURALHY project.
- Integrity management tools have been developed for natural gas/hydrogen mixtures in the NATURALHY project. When used in conjunction with data from the other work packages and from the pipeline operator, these tools will provide the user with information about the additional or mitigating measures required to maintain an acceptable level of integrity for the pipeline system when adding hydrogen. A software tool to assess the Probability of Failure (POF) for a pipeline, based upon the strategy for integrity management used by a pipeline operator, has been developed and will be further improved in the coming period. These results are of importance in assessing the

economic consequences of mixing hydrogen with natural gas, and also to convince pipeline operators that the NATURALHY approach is worth adopting.

- Carbon-based membranes have been found to have the capability of separating hydrogen from mixtures at high flow rates to give around 98% hydrogen purity, while very pure hydrogen (>99.9%) have been obtained with laboratory scale thin palladium-based membranes. These could prove to be crucial results for those cases where end-users wish to withdraw hydrogen selectively, at different required levels of purity from the gas mixture.
- The theoretical separation efficiency of palladium-based membranes is low at the prevailing line conditions. Therefore, studies have been performed to assess the feasibility of systems based upon a combination of carbon-based and palladium based membranes. Large scale pressure swing absorption (PSA) units are currently being used for the purification of hydrogen. Information regarding the energy consumption and capital cost of these PSA units will be used for a comparison with the specification of the combined carbon/palladium based membrane separation systems.
- Life cycle and socio-economic assessment is an essential means of determining the overall costs and benefits of distributing hydrogen via the existing European Union natural gas pipeline system. A standard format has been developed for workbooks which enable such assessments and initial versions of workbooks have been produced for the construction, operation, maintenance and decommissioning of existing natural gas networks. These provide the essential basis for simulating the injection, separation and use of hydrogen (in pure or mixed forms) in existing natural gas networks.
- The Decision Support Tool (DST) provides the means for integrating the technical results, subsequent tools and workbooks generated by the NATURALHY project. Fundamental details of the DST have been elaborated further, essential links with the outcomes of other work packages have been established and demonstration elements have been produced.

2.3. Concluding Remarks

The maximum allowable percentages of hydrogen related to the technical conditions mentioned above must be viewed from a technical perspective in a situation that no additional or mitigation measures are taken. In this case up to a 20% hydrogen level might be feasible in some European countries. However, investigation of the implications of designing and applying additional measures has already commenced within the NATURALHY project. Preliminary results indicate if pipelines are inspected more often with improved inspection tools, it might be possible to transport more than 20% of hydrogen with the same probability of failure as currently exists, albeit at somewhat higher costs. Also, if additional safety measures are implemented, current safety standards might be maintained with more than 20% hydrogen. If the older existing appliances are replaced,

higher hydrogen levels might be achievable in the end use market. All these additional costs will have to be reviewed from the perspective of the alternative option: the construction of an entirely new hydrogen transport and delivery system which inevitably will lead to very large investments in the order of hundreds of billions of Euros. These questions will be answered in the coming final period of the NATURALHY project when all the results from the technical work packages will come together for incorporation in the DST, with the LCA workbooks, that will be further developed and delivered in the final project period.

Finally, one has to bear in mind that all results mentioned above are based upon the investigations carried out within the current large scope of the NATURALHY project. A number of items were not addressed in the NATURALHY project as priority was given to the most important asset: the extensive pipeline grid. As it now appears, the use of the existing natural gas pipeline grid might be possible to a certain extent, and with mitigating measures even higher levels of hydrogen might be feasible. Therefore further research focused on a number of additional items like; the production and injection of hydrogen, the safe and reliable operation of the existing compressor stations, pressure reduction valves, sealings and joints in main transmission lines, might be justified. These additional items will be identified in the final report of the NATURALHY project and be mentioned as recommendations for further research.

2.4. Acknowledgement

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3. REFERENCES

For more details regarding the NATURALHY project please visit the following website: www.naturalhy.net