ASSESSING THE DURABILITY AND INTEGRITY OF NATURAL GAS INFRASTRUCTURES FOR TRANSPORTING AND DISTRIBUTING MIXTURES OF HYDROGEN AND NATURAL GAS

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ABSTRACT

Extensive infrastructure exists for the transport of natural gas and it is an obvious step to assess its use for the movement of hydrogen. The Naturalhy project's objective is to prepare the European natural gas industry for the introduction of hydrogen by assessing the capability of the natural gas infrastructure to accept mixtures of hydrogen and natural gas. This paper presents the ongoing work within both Durability and Integrity Work Packages of the Naturalhy project. This work covers a gap in knowledge on risk assessment required for delivering H2+natural gas blends by means of the existing natural gas grids in safe operation.

Experiments involving several parts of the existing infrastructure will be described that are being carried out to re-examine the major risks previously studied for natural gas, including: effect of H2 on failure behaviour and corrosion of transmission pipes and their burst resistance (link to the Work Package Safety), on permeability and ageing of distribution pipes, on reliability and ageing of domestic gas meters, tightness to H2 of domestic appliances and their connexions. The information will be integrated into existing Durability assessment methodologies, originally developed for natural gas.

An Integrity Management Tool will be developed taking account of the effect of hydrogen on the materials properties. The tool should enable a cost effective selection of appropriate measures to control the structural integrity and maintaining equipment. The main measures considered are monitoring, non destructive examination (pigging and non pigging) and repair strategies. The tool will cover a number of parameters, e.g.: percentage of hydrogen in the gas mixture, material of construction, operating conditions and condition of cathodic protection. Thus, the Integrity Management Tool will yield an inspection and maintenance plan based on the specific circumstances.

1 INTRODUCTION

Extensive infrastructure exists for the transport of natural gas and it is an obvious step to assess its use for the movement of hydrogen. The Naturalhy project is a major "Integrated Project" which has been selected for funding by the European Commission within the Sixth Framework Programme (started in May 2004). The objective is to prepare the European natural gas industry for the introduction of hydrogen by assessing the capability of the natural gas infrastructure to accept mixtures of hydrogen and natural gas. Many aspects of compatibility with existing natural gas infrastructure need to be considered, including safety.

This paper presents the ongoing work within both Durability and Integrity Work Packages of the Naturalhy project. This work covers a gap in knowledge on risk assessment required for delivering H2+natural gas blends by means of the existing natural gas grids in safe operation. The strategy adopted for the Durability and Integrity work within Naturalhy is to gain an understanding of the changes induced by injecting H2 in the natural gas on the Durability of the existing infrastructures and associated risk assessment and to update the Tools for Integrity Management. An extensive literature survey [1] was carried on for fitting the work programme to the most relevant experimental and numerical studies.

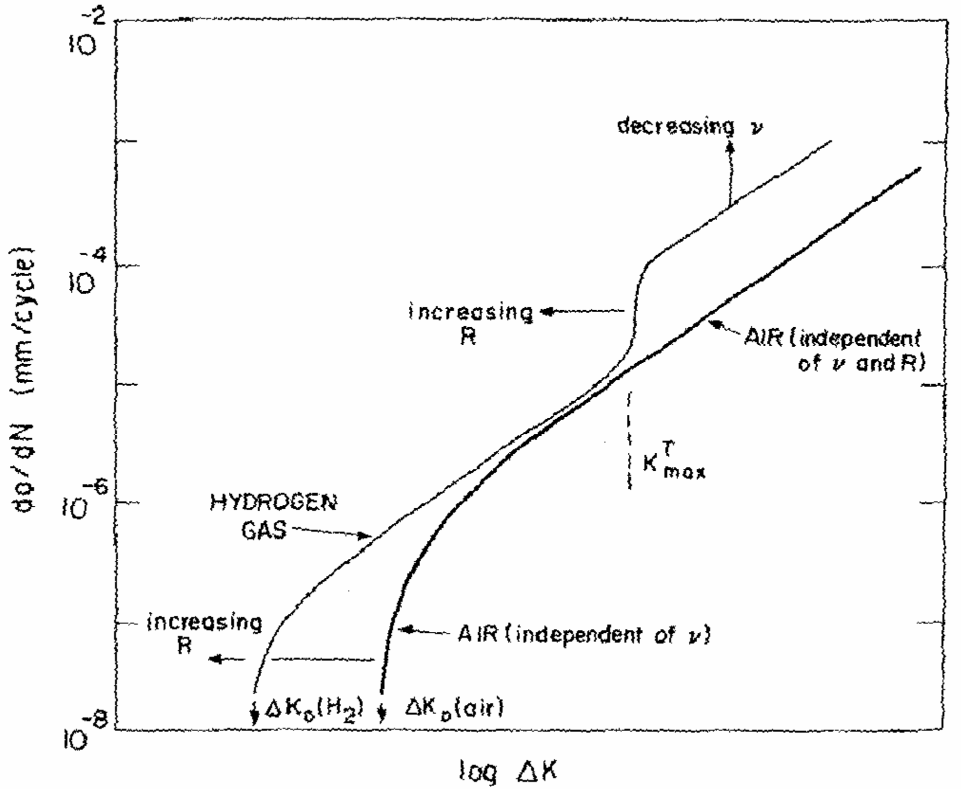
2 DURABILITY OF THE EXISTING NATURAL GAS GRIDS FOR H2 DELIVERY

The existing natural gas system has been designed for natural gas. The physical properties of hydrogen differ from natural gas and consequently the impact of hydrogen added to natural gas on the durability of the materials of the grids should be studied. According to the type of the materials of the pipes and therefore their interaction with hydrogen, several approaches for up-dating the major risks previously managed with only natural gas are followed.

2.1 Durability of steel for transmission pipes with H2

Transmission pipes in the existing natural gas grids operates under high pressures for example from 40 bar up to 100 bar. The steels (low carbon steels) used for building the transmission grids have been developed with higher and higher mechanical strength; the steel X42 is one of the oldest, used in the 60's and today operators start to use the X80. But higher is the yield strength, lower is the resistance to crack growth. This risk is well managed for natural gas, and should be assessed for hydrogen. Although the interaction of hydrogen with steels has been largely studied, the aim of using the steel grids designed for natural gas for transport of H2 requires extended studies about the effect of hydrogen on the properties of these steels and understanding of the mechanisms.

Hydrogen embrittlement and its effect on toughness and fatigue behaviour (figure 1); it is well known that hydrogen might initiate brittleness of steel pipes, which affects the failure resistance of the pipe and has consequences for the safety and the lifetime of the pipeline. The degradation mechanism of a pipeline by hydrogen is a very complex matter: for instance, preliminary experiments showed that the sensitivity of a pipeline for degradation by hydrogen is effected by amongst others the operational history of the pipeline. It was proven that a pipeline that has been operated under fluctuating pressures is more sensitive to degradation than a pipeline of the same material that has been operated under a more or less constant pressure.



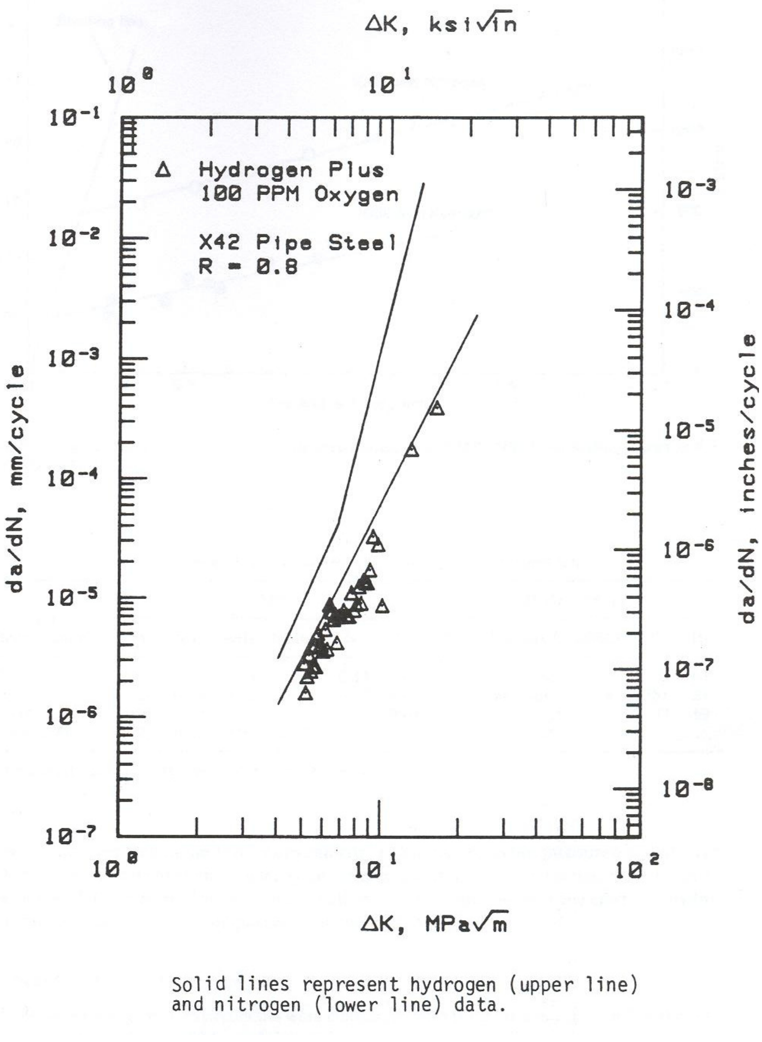


Figure 1. Effect of gaseous hydrogen on resistance of pipe steel to crack growth in fatigue loading [2, 3].

- Tests will be executed on laboratory specimens as well as a few tests on real structures containing defects, to quantify the effect of hydrogen on structures with typical in-service damage; measurement of fracture toughness and fatigue crack growth on steels with defects (welds, gouges, cracks, corrosion pitting) and without defects.

- Moreover the effect of addition of H2 on the evolution of the defects existing in the pipes will be investigated, and the existing defect assessment criteria will be adapted to take into account an increasing percentage of H2 in the natural gas.

- Some demonstrative tests will be carried on at full-scale under H2 pressure; fatigue tests and burst tests on parts of pipes with well-controlled defects. The results will be exchanged with the Work Package on Safety).

- The special case of the rapid propagation of crack, following the opening of the gas pipe, will be studied by numerical modelling. It is expected that due to their different thermo-dynamical properties, the crack arrest will happen sooner in case where hydrogen is present in the gas pipe.

2.2 Durability of polymer for distribution pipes with H2

The poly-ethylene (PE) is the mostly used material for local distribution of natural gas at low pressures, from 16 bar down to few mbar. The main concern about pipes made in polymer like the poly-ethylene (PE) is its permeability to H2 which may induce leakage of gaseous H2 and therefore a dangerous situation. Measurements were done on PE80 material samples in various conditions of pressure, H2 content and temperature. Results showed that H2 diffuses quicker than CH4 and with larger quantity (figure 2). Results will be used for calculating the potential leakages on distribution network and these data will be exchanged with the Work Package on Safety.

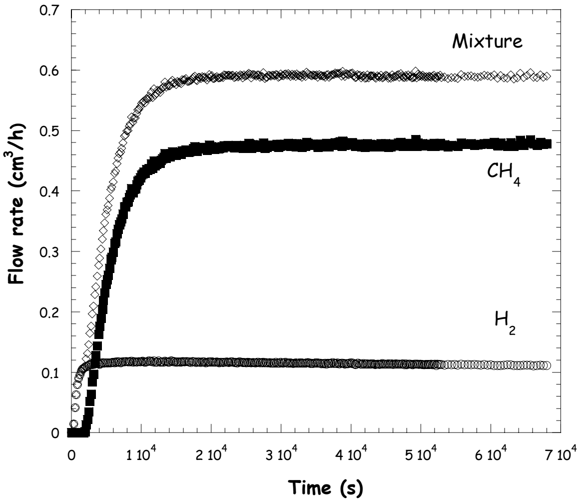


Figure 2. Permeation of PE80 to hydrogen, methane and their mixture (90%CH4-10%H2) (at 80°C and 21 bar).

Literature survey is quite fine on ageing of PE in H2 gas atmosphere. This subject will be studied under H2 pressure (up to 100 bar) with different H2 content in CH4 (up to 100%). The ageing tests will be accelerated by means of temperature increases (up to 60°C). Tests at 10°C will simulate the actual thermal conditions. Mechanical and physical-chemical techniques will be used for investigating the evolution of the PE properties and micro-structure with ageing conditions.

2.3 Durability of domestic gas meters

The most common domestic gas meters are membranes meters, made with a polymeric membrane which is sensitive to H2 permeation. Several potential effects of H2 are expected;

- Potential influence on metering accuracy; the fact that hydrogen particles are smaller than natural gas ones may cause leakages through the membrane. In such a case, the measuring accuracy would be impaired,
- Potential influence on safety; the dimensions of hydrogen particles may lead to a leakage into the atmosphere through connection sealing,
- Potential influence on durability; Hydrogen physicals characteristics may damage the internal parts of the meter.

Then, the meters will be tested regarding their reliability for H2 metering and ageing behaviour of the membrane in presence of hydrogen.

2.4 Durability assessment tool

All results obtained within the Work Package on Durability will be used for providing the lifetime estimation for the different parts of the gas networks (transmission, distribution and inner grids) and for adjusting the existing lifetime models for pipelines designed for natural gas. The results will be synthesized with the aim to develop sufficient knowledge in order to produce the assessment tool; new software tool for predicting damage impact on pipeline strength, verification of software simulation, and user guidelines.

It will be useful for simulating the most risky situations (severe defects, weak material pieces or joints, H2 release, etc.), so that the safety resulting from the handling of mixtures of hydrogen and natural gas can be determined.

Furthermore, the results are an essential input for the Work Package on Integrity.

3 INTEGRITY MANAGEMENT

3.1 Integrity management of existing pipelines

The most common integrity problems in the existing transmission pipelines include external corrosion and mechanical damage. Internal corrosion has not been a significant issue in most instances due to a strict control of moisture content in the natural gas to meet consumer specifications. Similarly, manufacturing and construction defects are not normally a problem as the quality control during construction and a hydrostatic test ensure that no critical defects are present after construction.

Generally speaking, crack like defects or mechanical gouges are treated by grinding to remove the possibility of crack propagation. Once the defect is removed, the remaining strength of the pipe is assessed using one of the recognised techniques for calculating the effects of a metal loss defect on the strength of the pipe.

If a metal loss defect (non-leaking) is deemed to be critical and in need of repair, the normal methods to apply are for instance a non-welded pipe sleeve or a clock-spring type repair. Both methods are based on a localised mechanical reinforcement of the pipe to compensate for metal loss while avoiding interference with the cathodic protection system or changing the properties of the pipe metal. Fundamental in any repair is that the corrosion process be stopped with a good coating to ensure that the defect in question does not grow.

3.2 Defect criticality

With regard to the foreseen application of hydrogen to natural gas, one of the most interesting issues is the so-called defect criticality. The current practice for determining whether a defect is critical and needs to be repaired are based on defect geometry, material properties and to a certain extent service use. However, if the hydrogen or hydrogen mixture within the pipeline acts to change the pipe material properties, in particular with respect to crack propagation, these criteria may need to be revised. Therefore, the critical issue to be investigated is related to the question which type of defects and up to which size can be judged to be acceptable. Within the population of the current acceptable defects, there may be a certain group that become critical under hydrogen service.

Another aspect which will be of interest, will be the potential for acceleration of fatigue - type failures. Typically in a natural gas transmission system, the number of pressure cycles is so small that defects surviving the hydrostatic test after construction will not fail from fatigue during the life of the pipeline. Thus a number of pipe material or weld defects may exist in today's pipeline networks that are non-injurious and essentially undetectable with the inspection technology in use. If it can be shown that these types of defects may grow more rapidly in the presence of hydrogen, a new inspection technique may have to be adopted to detect and eliminate these defects in a timely fashion.

The various effects from hydrogen on the materials behaviour are depicted in figure 3.

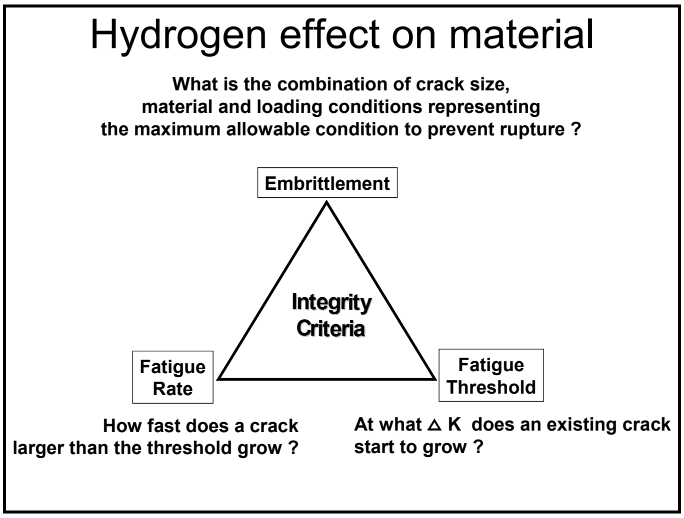


Figure 3. The influence of hydrogen on the material behaviour.

3.3 Development of inspection effectiveness

It is expected that hydrogen addition will have a certain effect on the materials behaviour although no results are currently available to support this expectation. Especially, the fatigue threshold value is expected to decrease. Therefore, it will be important to verify whether the existing inspection tools (for pigging e.g. Magnetic Flux Leakage) will be capable of detecting the smaller defect sizes. Possibly, improvements on the detection capability of existing inspection techniques are needed to meet the more stringent detection requirement. The inspection methods can be split in inspection method for piggable pipelines and non-piggable pipelines. A large testing and validation programme is foreseen to demonstrate the capability of existing techniques.

3.4 Development of repair strategies

Certain non-acceptable defects can be repaired by different kinds of techniques like grinding, weld deposit, metallic sleeves, composite sleeves to save money comparing to the cost of cut and replacement of pipe defective sections.

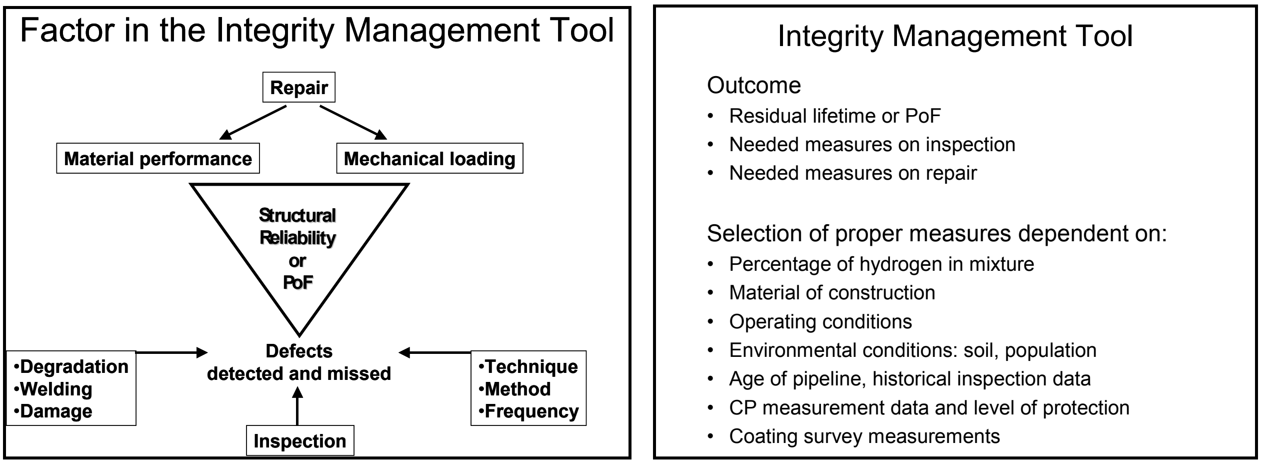
Due to mechanical steel properties affected by hydrogen around the defects, the current repair criteria for gas pipelines should be changed. For example, the steel toughness affected by hydrogen could modify the weld deposit conditions, the maximum acceptable sizes of grinding, and the maximum acceptable sizes of defects to repair by sleeves.

In addition, it will be interesting to consider the possibility of crack formation under a mechanical reinforcement repair. These repairs generally accept a certain degree of plastic deformation around the metal loss defect as the pipe expands and transfers the excess stress to the mechanical reinforcement. The amount of plastic deformation depends on the type of reinforcement and the quality of the installation process. In considering a hydrogen mixture, it should be verified that the pipe will continue to support these small plastic deformations without cracking. A crack, if it forms under the mechanical reinforcement, could propagate along the pipe and away from the area being reinforced.

3.5 Integrity Management Tool

At present asset owners make use of Integrity Management Tools to support the process of decision-making and selection of cost effective, appropriate measures to control the structural integrity. Possible measures are monitoring, non destructive examination (pigging and non pigging), excavations and various repair strategies. The Integrity Management Tool should integrate all the available data and models to enable risk management. The tool can be used to demonstrate the effect of influencing factors on integrity, i.e. the probability of failure of a certain pipeline system, see figure 4.

In the project a tool will be developed consisting of models and data in order to take account of the presence of natural gas containing hydrogen. The tool will cover a number of parameters, e.g.: percentage of hydrogen gas mixture, material of construction, operating conditions and condition of cathodic protection. Eventually, the Integrity Management Tool will yield an inspection and maintenance plan based on the specific circumstances.



Integrity Management Tool

Outcome

- Residual lifetime or PoF
- Needed measures on inspection
- Needed measures on repair

Selection of proper measures dependent on:

- Percentage of hydrogen in mixture
- Material of construction
- Operating conditions
- Environmental conditions: soil, population
- Age of pipeline, historical inspection data
- CP measurement data and level of protection
- Coating survey measurements

Figure 4. The Integrity Management Tool.

4. CONCLUSION

The addition of hydrogen in pipes and appliances originally designed for natural gas induces large campaigns of testing for determining the characteristics and performance of the materials used since the 60’s or younger in new conditions, and then for determining their lifetime in case of delivery of H2-natural gas mixtures in safe conditions. Understanding of the mechanisms of interaction with H2 is an other important point. Data will be used also for up-grading the existing assessment tools, and guidelines.

The presence of hydrogen in natural gas can decrease in certain cases the mechanical integrity of steel pipelines by local embrittlement in high plastically strained zones, e.g. near defects. The updated defect assessment criteria determined will be more severe than for the existing natural gas situation. So, the acceptable sizes of certain defects will diminish.

Inspection techniques and methods will have to be improved towards a better reliability and more precise detection to maintain a high level of safety and to enable monitoring the degradation for transmission pipelines containing hydrogen – natural gas mixtures,. In addition, repair methods and integrity management will be adapted. The new knowledge will be implemented in an Integrity Management Tool for resource management.

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