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Field Test of Hydrogen in the Natural Gas Grid

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It has become ever clearer that the resource of natural gas is an energy source which will be less important in the future due to limitations in natural reserves. In order to prepare for the future the gas industry is looking at alternative gaseous fuels, one such fuel gas is hydrogen.

In order to prepare for a future use of hydrogen it became evident that very little information exists regarding the compatibility between long term exposure and transportation of hydrogen in steel gas transmission pipelines and polyethylene gas distribution pipelines. A program was therefore set to study the transportation in a small scale pilot grid at the field test facilities of the Danish Gas Technology Centre situated at the Scion-DTU research centre in Hörsholm, Denmark.

The test program included former used steel pipes from the Danish gas transmission grid and polymer pipes from the Danish and Swedish gas distribution grid.

The Project partners was Danish Gas Technology Centre, Borealis AB and FORCE Technology. Danish Gas Technology Center was project manager and responsible for operation of the field test. Borealis - one of the biggest suppliers of raw material from polyethylene for the production of pipes for e.g. pressure pipes for gas distribution - provided analytical services for the determination of compatibility problems between polyethylene pipes and hydrogen under long term exposure. FORCE Technology focused on dynamic testing and analysis of the steel pipes from the gas transmission grid.

1 Polymer Pipe Test and Analysis

A dominant part of the natural gas distribution grid consists today of polyethylene pipe due to its excellent track record as a reliable piping material with minimal maintenance. The reason for this is the inherent properties like its corrosion free nature, the possibility to create fully weldable systems, its high ductility and excellent low temperature properties.

The program was devised so that a part of the test grid was to be dug up each year and analyses were performed on the pipes. In this way any form of influence on the integrity of the polyethylene pipe would be detected. The pipes were analysed before exposure to hydrogen, then the pipes has been dug up after 1 year, 2 years, 3 years and 4 years of exposure. Some of the pipes have also previously been used in the Danish natural gas network. The oldest pipes have been subjected to natural gas for 20 years before exposure to H_2 in the pilot grid.

The analytical program was devised to detect any influence on the additivation of the polyethylene as this have an influence oxidative resistance. Furthermore the test pipes were analysed for possible degradation caused by extrusion of the material. The possible interaction between the antioxidant and hydrogen has been checked by the so called oxygen induction temperature (OIT), which shows the antioxidation effect of phenolic antioxidants.

The possible extrusion influence has been analysed by Fourier Transform Infrared analysis and a check of the carbonyl content on the inner surface of the pipes was performed.

Furthermore the study has focused on detecting possible changes in the structural composition the polyethylene. The materials for gas pipes are very high molecular weight materials, therefore rheology was chosen as this is very sensitive for changes in the high molecular weight part of the material. The rheology has been presented as a number of index, namely $\eta_{2,7\ KPa}$, $SHI_{2,7/210}$ and $\eta_{747\ Pa}$ this gives an indication of the molecular weight, the molecular weight distribution and the high molecular weight tail. The rheological analysis has been performed on an Anton Paar, Physica MCR350, in a plate/plate set up at 190 degree C. Also, Melt flow rate (MFR) and flow rate ratio (FRR) has been utilised to further detect any structural changes. The MFR analysis has been performed according to ISO 1133.

To complete the analysis the most important mechanical properties has been checked, in order to further strengthen that the analysis of the antioxidant interaction and the possible interaction to the polymer structure has been able to pick up any changes. The most important mechanical properties have been defined as: Tensile test, elongation at break, tensile modulus and slow crack growth, measured in the CTL test. Especially if changes takes place in the slow crack growth properties of the material this would be very negative as in practise the resistance to slow crack growth determines the potential life length of the pipe line system. The tensile tests and modulus has been performed according to ISO 527-2/1B and the CTL analysis has been performed according to ISO 6252-1992 fitted with a notch according to ASTM F 1473 at 60 degree C in a 10 % Igepal 720 water solution.

In this investigation two different classes of polyethylene pipes and materials have been studied, namely PE80 medium density polyethylene (MDPE) gas pipes and PE100 high density polyethylene (HDPE) gas pipes. The MDPE gas pipes have different manufacturing dates. Some of the PE80 gas pipes were manufactured in 1982. The PE100 gas pipes consist of two different pipes and materials. One pipe/pipe material is an orange single wall pipe, while the other was a two layer pipe with a natural coloured main inner pipe and a thin orange outer protective layer. The purpose of the outer layer is to provide a UV protective layer, an easy peelable layer before welding and protect the inner layer from outer damage. Also in the case of the PE100 gas pipes different manufacturing dates are present. The oldest pipe is from 2001.

Summary of the results:

In all of the pipes sampled from each of the years (no exposure, 1 year, 2 years, 3 years and 4 years) that has been analysed no surface oxidation has been found. This means that all pipes have been extruded according to industry praxis and no pre-damage has taken place.

The study of the antioxidant shows no indication of a deterioration of the stabilisation. This means that in the oxygen induction time (OIT) measurements at two temperatures we have not found any significant changes over the four years of exposure compared to a non-exposed material. The OIT values remains at a similar value throughout the 4 year test period within the accuracy of the measurement. Typical results after 1 - 4 years of exposure is approximately 22 min at 210 C and 50 min at 200 C for the PE80 samples and approximately 60 min at 210 C and 160 min at 200 C for the PE100 samples. The standard demand in EN1555, the PE gas pipe standard, is 20 min at 200 C which is also clearly surpassed by both the PE80 and PE100 material. The interpretation is that there is no interaction between the hydrogen and antioxidants or hydrogen and material over the investigated period. The results are valid for both the PE80 and the PE100 pipes.

The structure analysis also indicates that there is no interaction between hydrogen and the Polymer. Neither in the MFR/FRR analysis nor the rheological analysis is revealing any interaction between the polymer and the transported media, hydrogen. The structure of the polymer is intact according to the analysis made after four years of exposure. This is valid for both the PE80 and the PE100 pipe materials.

The mechanical analysis shows the same. The tensile tests, elongation at break and the elastic modulus as well as the slow crack growth show that no deterioration occurred due to the exposure to pressurised hydrogen during the four years of exposure.

In summary, according to the tests performed in this study, we have found strong indications that polyethylene gas pipes PE80 and PE100 can be used for transportation of hydrogen without any adverse long-term effects on antioxidants, polymer structure or the mechanical performance of the polymer pipes. The same indications have been found for both new and old pipes that has been used in the Danish natural gas distribution network for more than 20 years.

An additional remark: The gas distribution network consists of many other components and connections. The above conclusion only applies to the tested types of pipe material. Before introduction of hydrogen in the natural gas network all components and connections must be investigated.

2 Steel Gas Transmission Pipeline Test and Analysis

The object of the steel pipe test was to see the effect on fatigue life of existing natural gas transmission lines with hydrogen gas being added to natural gas. The test and analysis focused on the effect of hydrogen on fatigue cracking in pipeline girth welds.

Full scale tests was performed using cut-out API 5L X70 pipe sections 20 inch diameter by 7 mm WT from the Danish natural gas transmission system. The pipe sections contained field girth weld made during the installation of the pipe line in eighties.

The internal test environment consisted of 100% hydrogen gas at fluctuating pressures representing the daily peak to peak variation in the gas transmission line. The maximum pressure was 70 barg and the maximum pressure amplitude used was 30 bar.

2 test series were conducted with increasing pressure amplitude from 20 barg to 30 barg.

The pressure cycle variation frequency was less than 0,0017 Hz. and each test serie was run for 15.000 or 30.000 cycles. 15.000 cycles corresponds to 40 years operation with one pressure cycle per day.

The girth welds were checked prior to test and again after the completed test cycle by ultrasonic examination. If no cracks were observed the test specimen continued in test for the next period.

Test series 1 was completed in 2008 and test series 2 was completed in 2009.

The girth welds has been dissected and subjected to metallographic examination in addition to the ultrasonic testing in order to describe possible defects and defect growth in the weld zones. The dynamic testing equivalent of 80 years with two times the maximal pressure variations found in the danish gas transmissionssystem (that is 2 x 15 bar equal to 40 to 70 bar for 30000 cycles) has shown no defect growth.

References

[1] Andersen, Paw, Celia Juhl, Lars Bo Pedersen, Asger N. Myken, Henrik Iskov: Hydrogen as an energy carrier. (In Danish with English summary only). Dansk Gasteknisk Center a/s. 1999. ISBN 87-7795-172-7.

[2] Iskov, Henrik: The suitability of the gas grid for distribution of pure hydrogen. (In Danish with English summary only). Dansk Gasteknisk Center a/s. 2004. ISBN 87-7795-253-7.

[3] Jensen, Jan K. and Iskov, Henrik: Field Test of Hydrogen in the Natural Gas Grid. World Gas Conference. 2006.