Field test of hydrogen in the natural gas grid

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Project goals

- *The purpose* of this project was to reveal the possibilities of transport of hydrogen via the existing Danish natural gas grid. The investigation only covers the distribution grid. For this purpose, a standalone "miniature gas grid" was built. That means:

- Testing used materials, components and connections from the natural gas distribution grid by exposing them to pure hydrogen for at least one year.

- Leakage rates and oxygen penetration.

- Steel pipes (19 bar) and plastic pipes (PE, 4 bar) and connections.

- Residential installation (20 mBar) and connections.

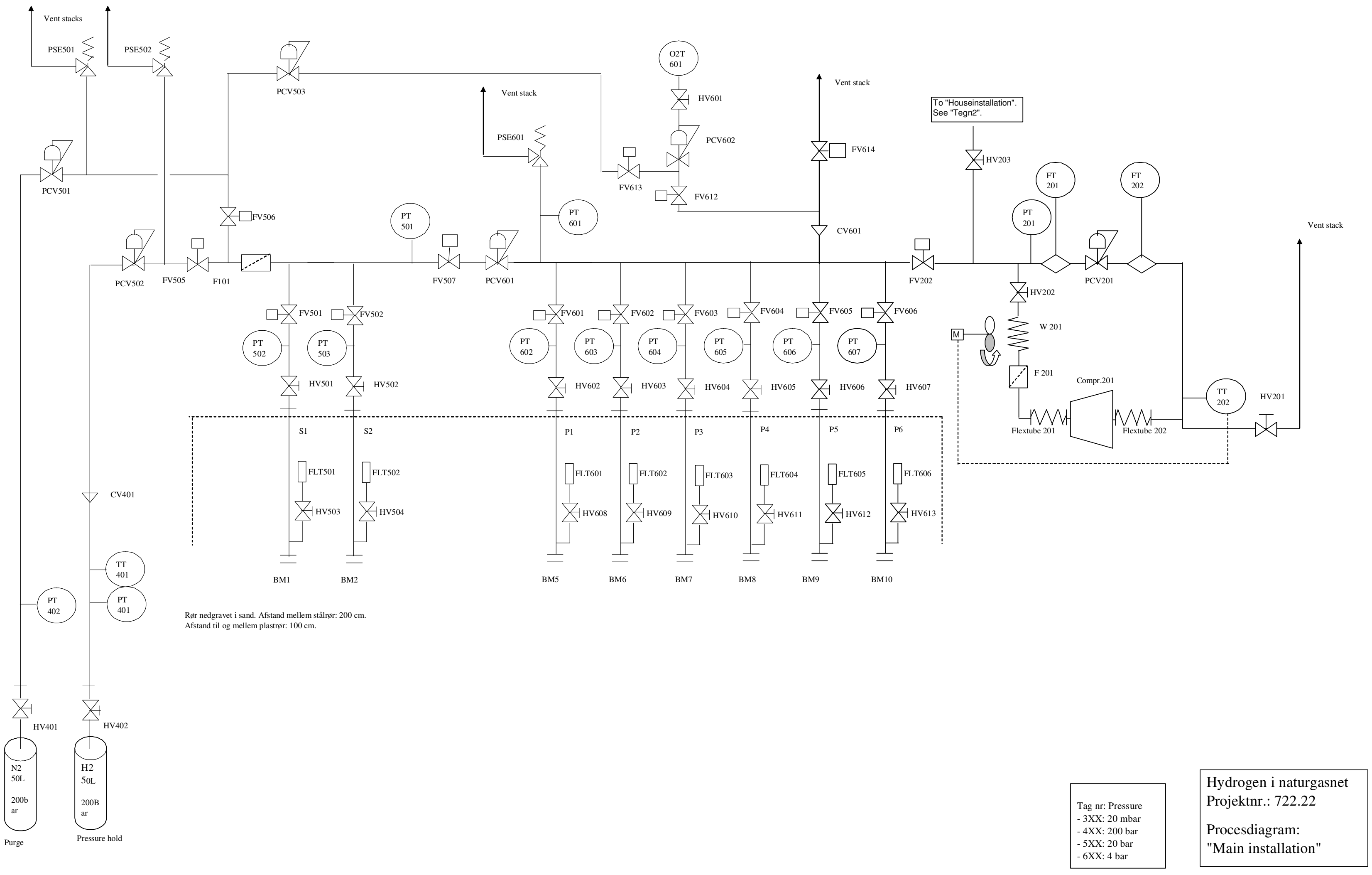
- Gas meters: Stability and precision of industrial gas meters as rotational and turbine types and household bellow types.

Test set up

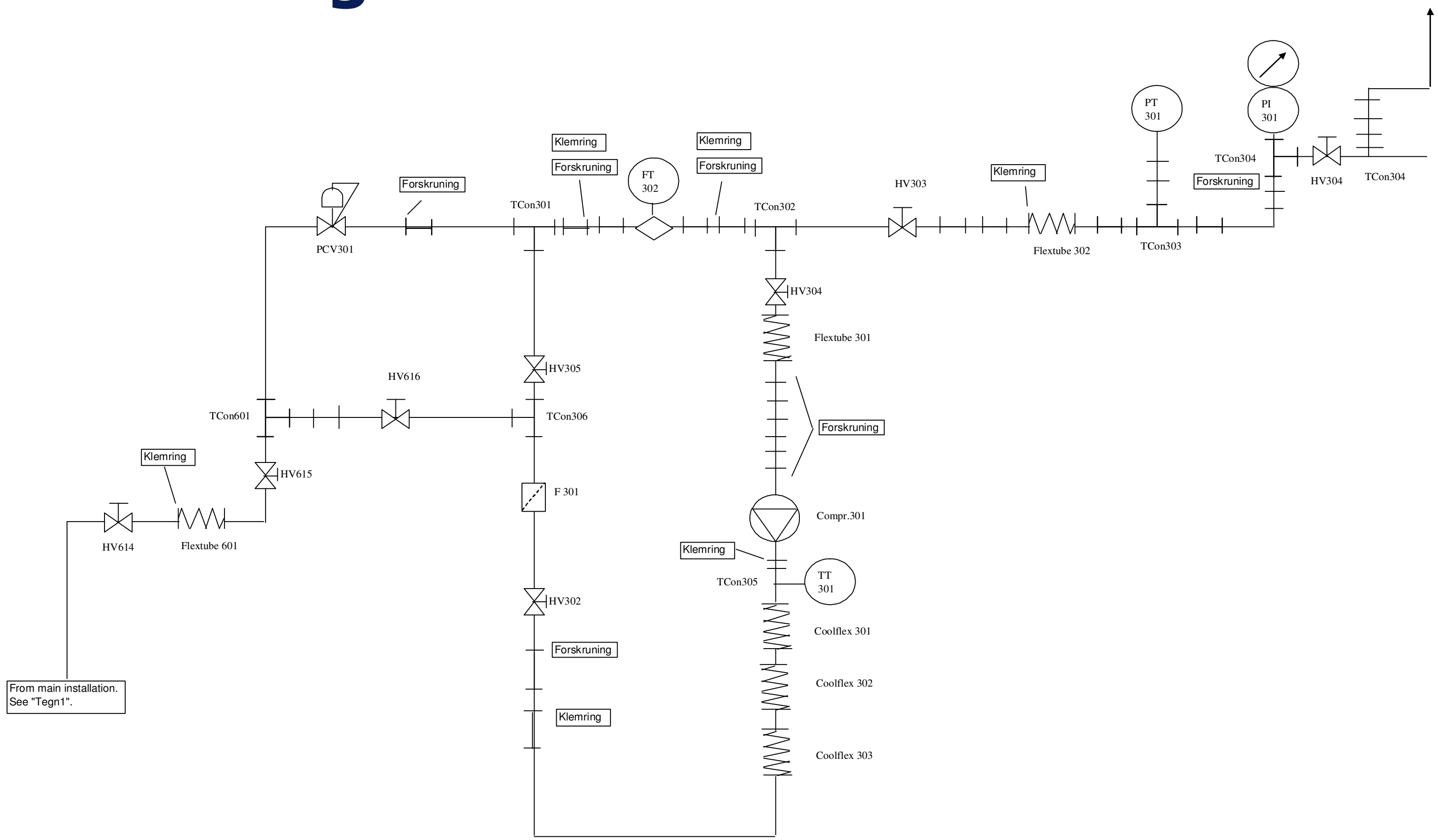
Grid facilities for distribution of hydrogen; test of gas meters, and systems for control, regulation and monitoring of the test facility were developed by DGC.

Steel and plastic pipes from the existing gas distribution grid were adapted for a small standalone gas grid, constructed according to existing standards and authority regulations by the Greater Copenhagen Natural Gas Company (HNG).

Proces Diagram: Main Installation



Proces Diagram: House Installation



Tag nr: Pressure
- 3XX: 20 mbar
- 4XX: 200 bar
- 5XX: 20 bar
- 6XX: 4 bar

Hydrogen i naturgasnet
Projektnr.: 722.22

Procesdiagram:
"House installation"

Material testing of hydrogen exposed components: Plastic pipes

- Plastic pipes tested for hydrogen penetration in pipe wall
- Weldability
- Gas chromatographic analysis for hydrogen
- Tensile strength
- Pressure testing
- Testing of electro and friction weldings
- All testing is compared to non-hydrogen exposed pipe samples
- Test includes both new and 20-year-old plastic pipes

Material testing of hydrogen exposed components: Steel pipes

- Tensile strength
- Metallographic analysis
- Surface analysis XRD/XRF
- Weldings tested
- All test compared to non-hydrogen exposed pipe samples

Testing of hydrogen exposed gas flowmeters

- Analysis of field flow measurement
- Recalibration at reference laboratory
- Disassembly and checking of gaskets and bellows
- Analysis of lubrication oil and grease for degradation

Installation of plastic and steel pipes

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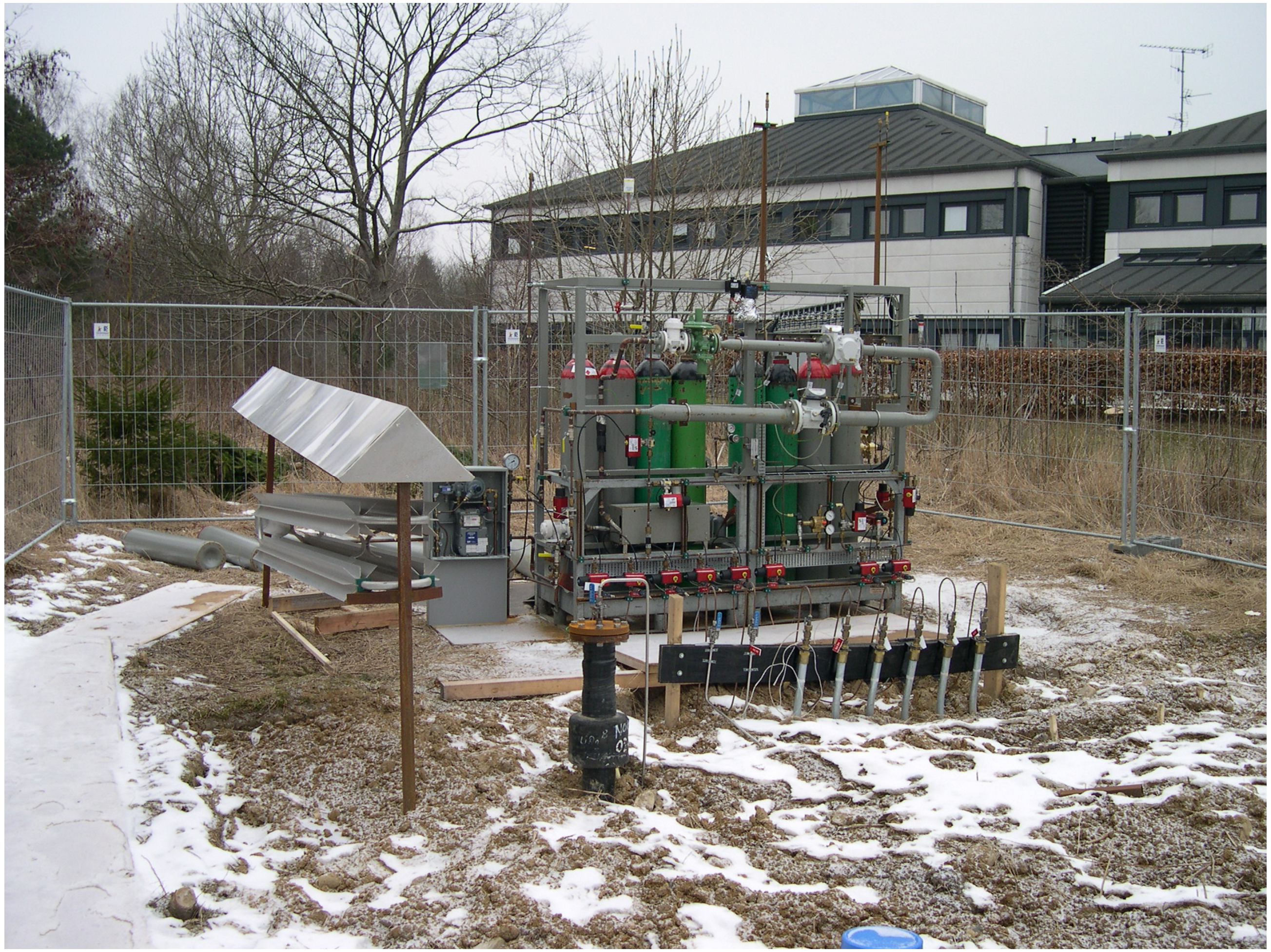
Hydrogen distribution system and gas meter test cycle

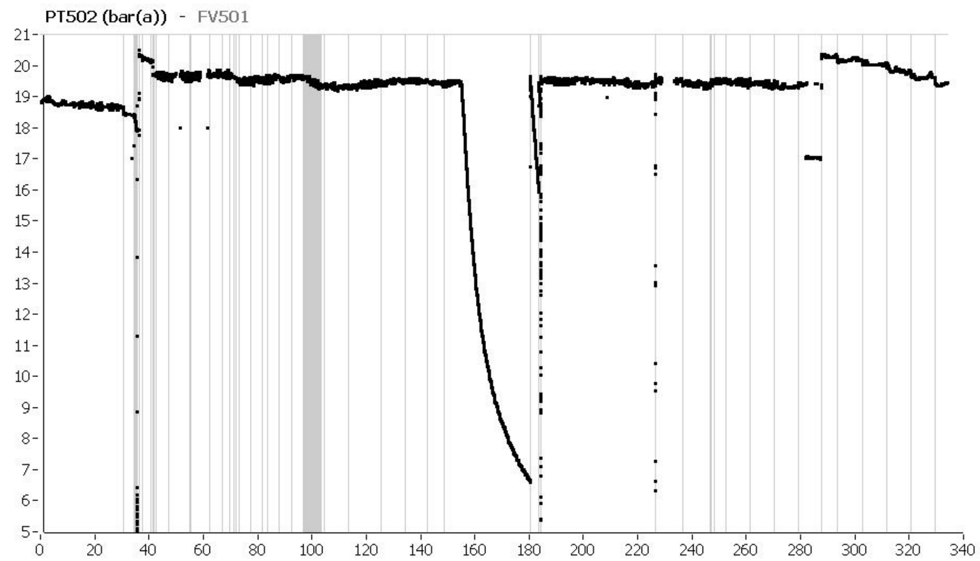


Test results, an overview

- Operation for 12 months without significant problems.
- Initial leak test during installation showed that about 50% of a widely used plastic coupling (4 bar PE grid) was leaking heavily. An alternative make solved the problem.
- Turbine type gas meters showed remarkable dependence of temperature.
- Oxygen penetration does not seem to be a problem.
- A few leaks were detected after 6 months of operation: Threaded connections only.
- No long-time leaks in steel pipes and only moderate leaks in polymer pipe system.
- Indication of increased leaks from residential system.

Test results, steel pipes

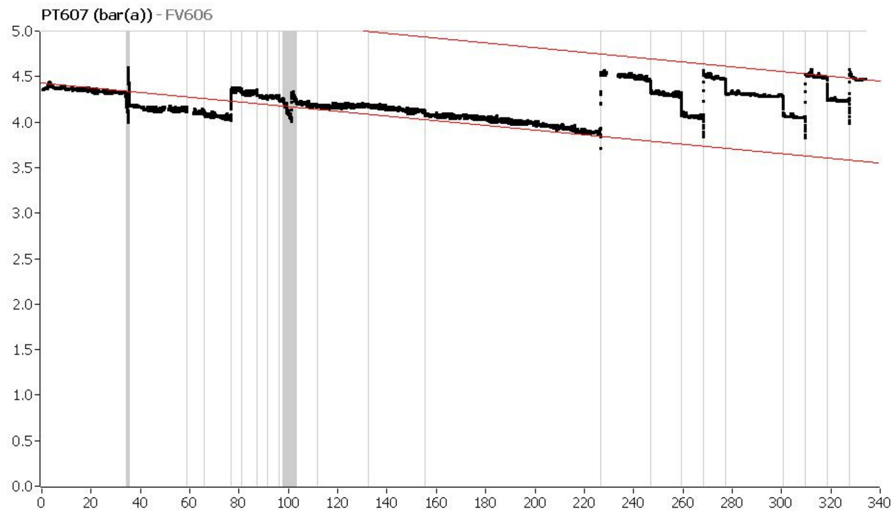
- 19 bar steel distribution pipes were tight throughout the entire test period, apart from a few times when a threaded joint or a valve became leaky.
- The steel material and welds in this material were completely unaffected by the hydrogen exposure.
- The tensile strength was unchanged, for basic material as well as for welding zones.



Test results, polymer pipes

- 4 bar plastic (PE) distribution pipes have been leaking at a constant leak rate throughout the entire test period, corresponding to a loss of 1 bar per year. The calculated permeability of hydrogen through the pipe wall amounts to approx. 20% of the measured leak.
- Practical welding tests have proven an unchanged weldability.
- The melting index for three out of four hydrogen exposed PE80 pipes dropped by 5-10%. This could indicate incipient changes to the material. No changes were found in the PE100 samples after the hydrogen exposure.
- OIT (oxygen induction) tests showed that the efficiency of the added antioxidant was reduced and that a few years of continued hydrogen exposure could reduce weldability to an unacceptable level for high-strength PE100 pipes.
- The tensile strength is unchanged, for basic material as well as for welding zones.
- Infrared spectroscopy has shown that the basic material did not change its chemical composition.

Leakage in polymer pipe system

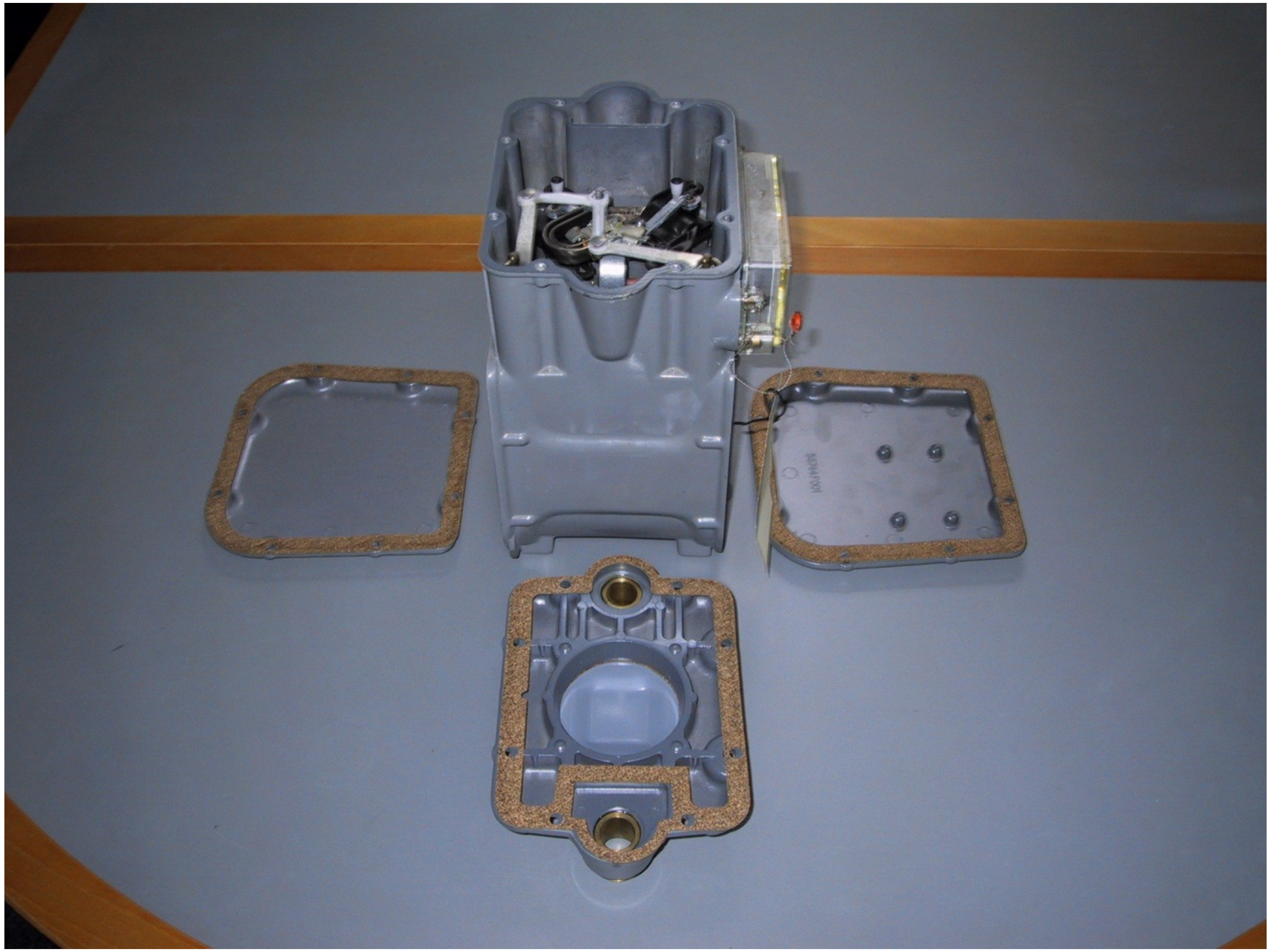


By comparing with permeability figures from literature we have found that in our system leakage is 5 times higher than permeation could account for. That means the primary source for leakage is connections, valves etc.

Natural gas meters used for hydrogen

- Industrial gas rotary type gas meters and the domestic gas meter maintained reliable results throughout the test period and were not damaged by the test operation.
- Recalibration at various factories has shown that all meters complied with specifications.
- Detailed investigations of sensitive components such as rubber gaskets etc. showed no signs of abnormal wear or incipient decomposition.
- During the test period a constant minor leak from the turbine gas meter was detected. The above detailed investigations showed no defects in the leaking components. I.e. a change of design is necessary when converting to hydrogen.

Residential natural gas meters used for hydrogen



Industrial natural gas meters used for hydrogen

Project partners and financing (Phase I)

- Danish Gas Technology Centre: Project management and operation of field test.
- HNG (Greater Copenhagen Natural Gas Company): Plastic and steel pipe preparation and installation etc. Build-up of residential installation.
- SGC/Tumab: Material analysis of exposed pipes.
- Norsk Hydro: Input of hydrogen knowhow and material analysis of steel pipes.
- These four partners, with support from the Danish Energy Authority, financed the project. The total cost was around 2,5 mio. DKK or approx. 0,5 mio. US$

Phase II (2005-2009) project

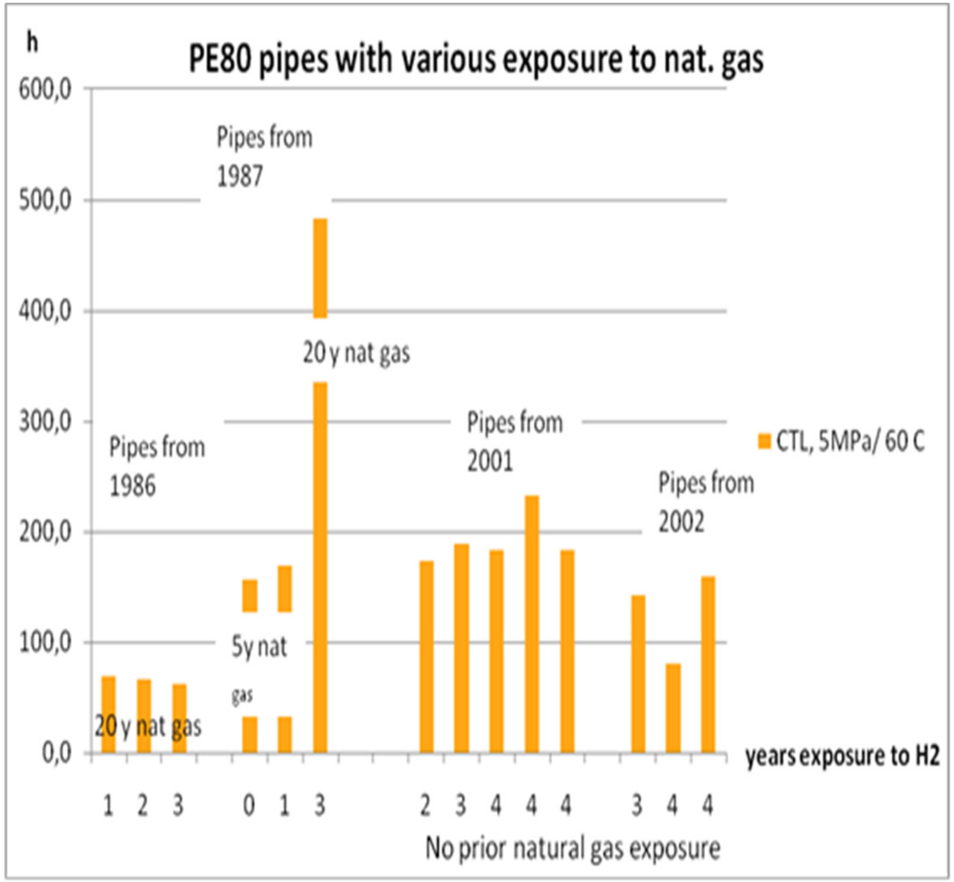
- *Test of polymer piping is ongoing for another three or four years. This time we have added more samples of different manufacturers and production year. Once a years samples are cut out and sent for very extensive material testing. Each time similar test are made to unexposed samples of polymer pipes, and results are compared. First round of analysis is underway right now.*

- *Dynamic testing of short samples of API 5L X 70 high-pressure gas transmission pipes is in preparation. Start up is expected 4 weeks from now. The idea is to expose the test pipe for varying pressures between 50 and 70 bar as seen as daily variation in the Danish gas transmission grid. In the test we shall of course speed up the variation to a cycle time of a few minutes. The ultimate goal is investigate the hydrogen compatibility of the gas transmission grid when this is dynamically pressure loaded. For instance, we investigate if normal size fractures develop faster than with natural gas.*

The analytical program

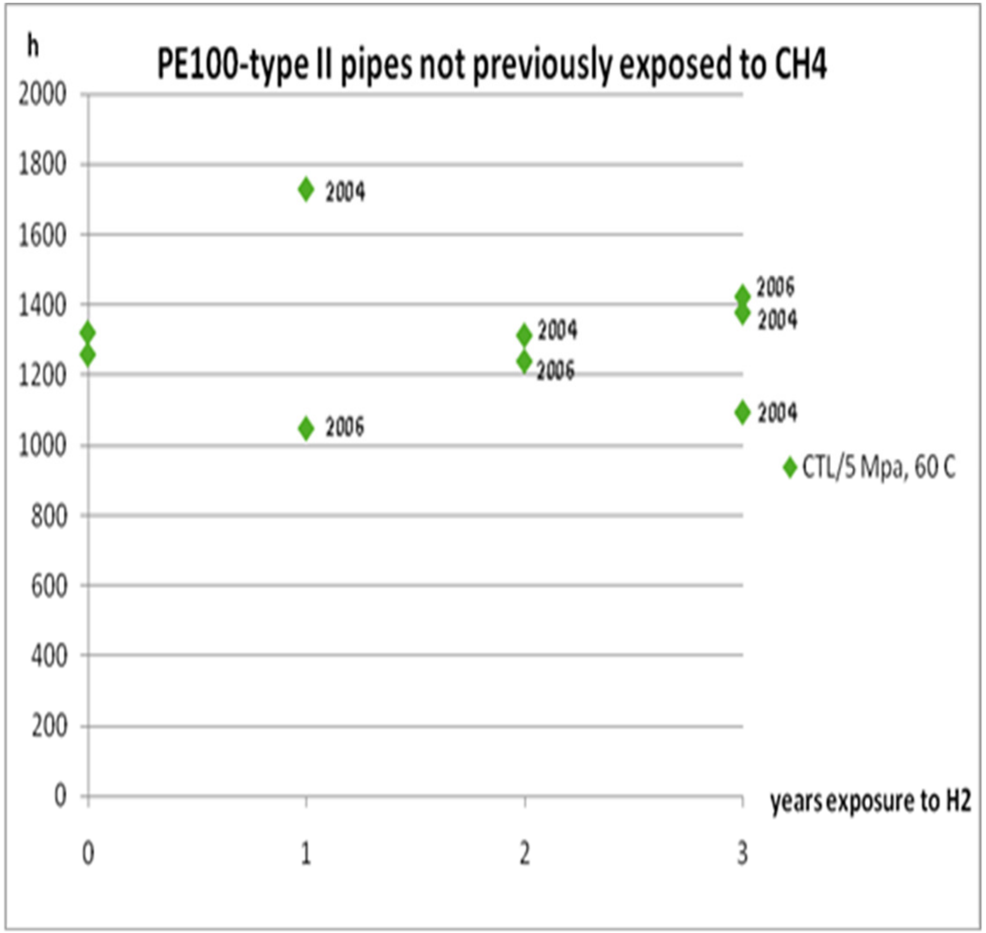
- The annual analyzing program consisted of:
- 1) Structural changes in the polymer. 2) Consumption of antioxidants 3) Change of Tensile properties 4) Change of slow crack growth properties of the material 5) Surface oxidation.
- The reason for this choice is that if no influences are detected in these properties then one can assume that polymer pipes are compatible with hydrogen and can safely be used, seen from a polymer structure-property-pipe property point of view.

Determination of slow crack growth, PE80



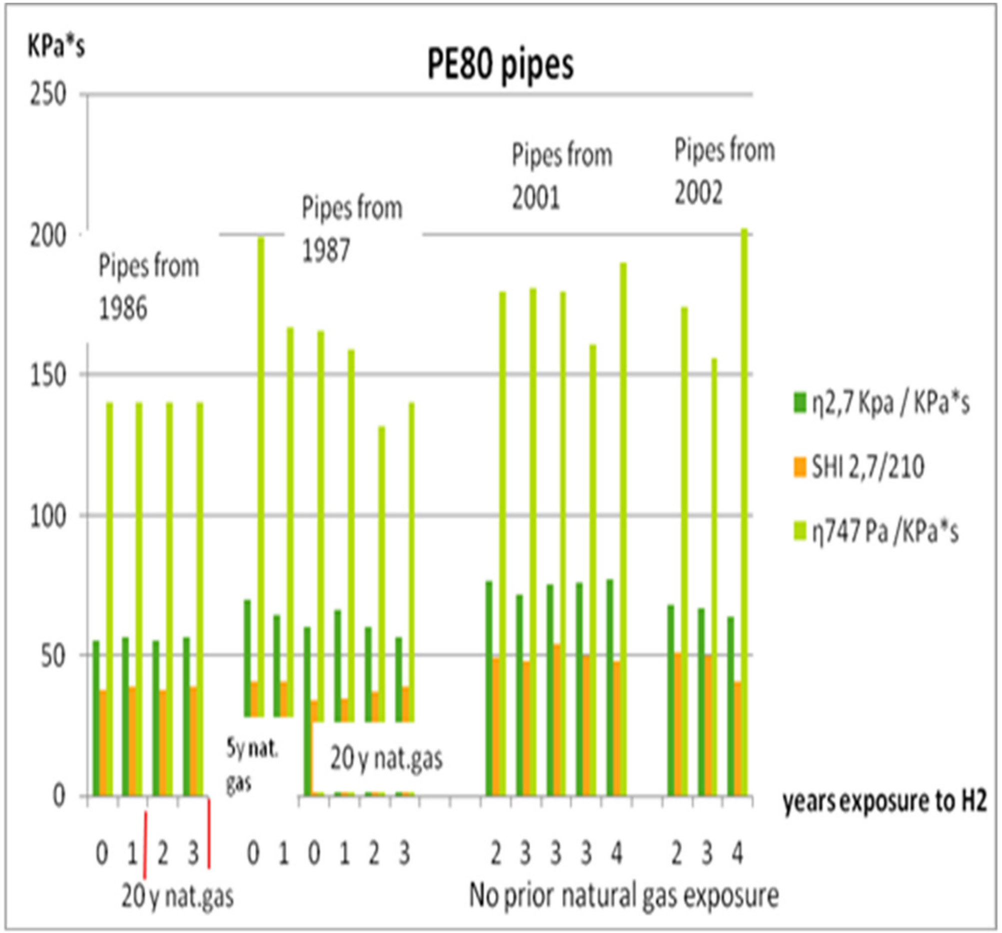
- In the ESCR testing there are no indications of changes of CTL test resistance to slow crack growth with the time in the pilot hydrogen grid. All variations are explained by the pipe manufacturing date and measurement variations, except for the probable outlier manufactured in 1987. The results are not depending on previous exposure to natural gas.

Determination of slow crack growth, PE100



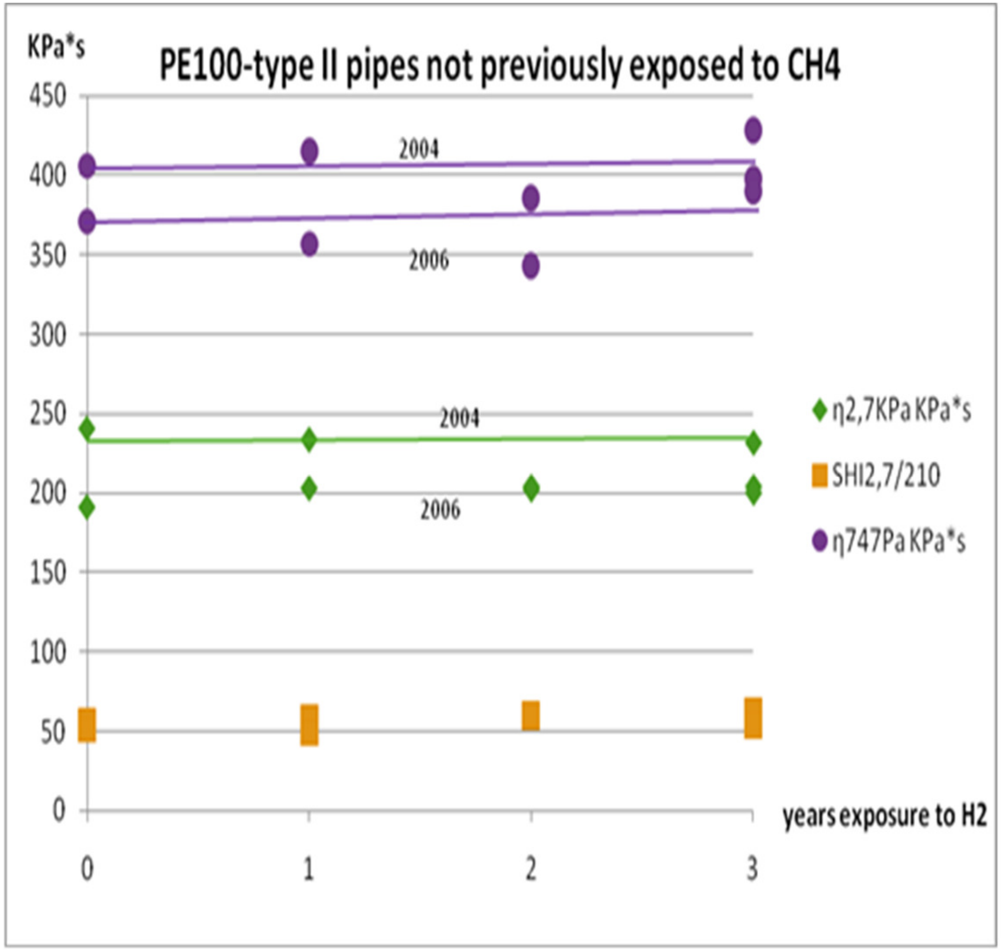
- Same conclusion as for the PE80 pipes: 5 years of pure hydroen exposure has not changed slow crack growth.

Determination of structural changes



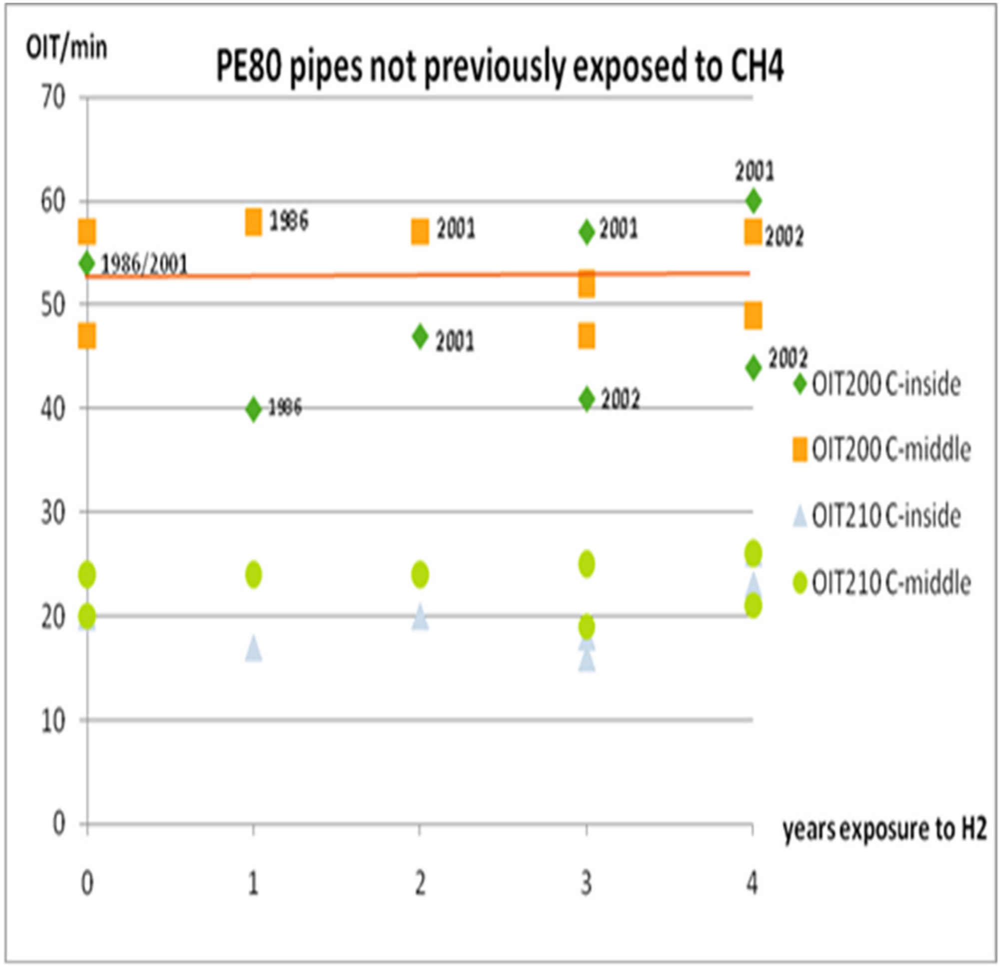
- Batch variations results in differences in molecular weight, Mw, molecular weight distribution, MWD and high molecular weight portion. The rheological result indicates clearly that different values relies on the basic quality level difference of the polymer manufactured in different years. Other changes within each group can be considered normal variations.

Determination of structural changes, cont.



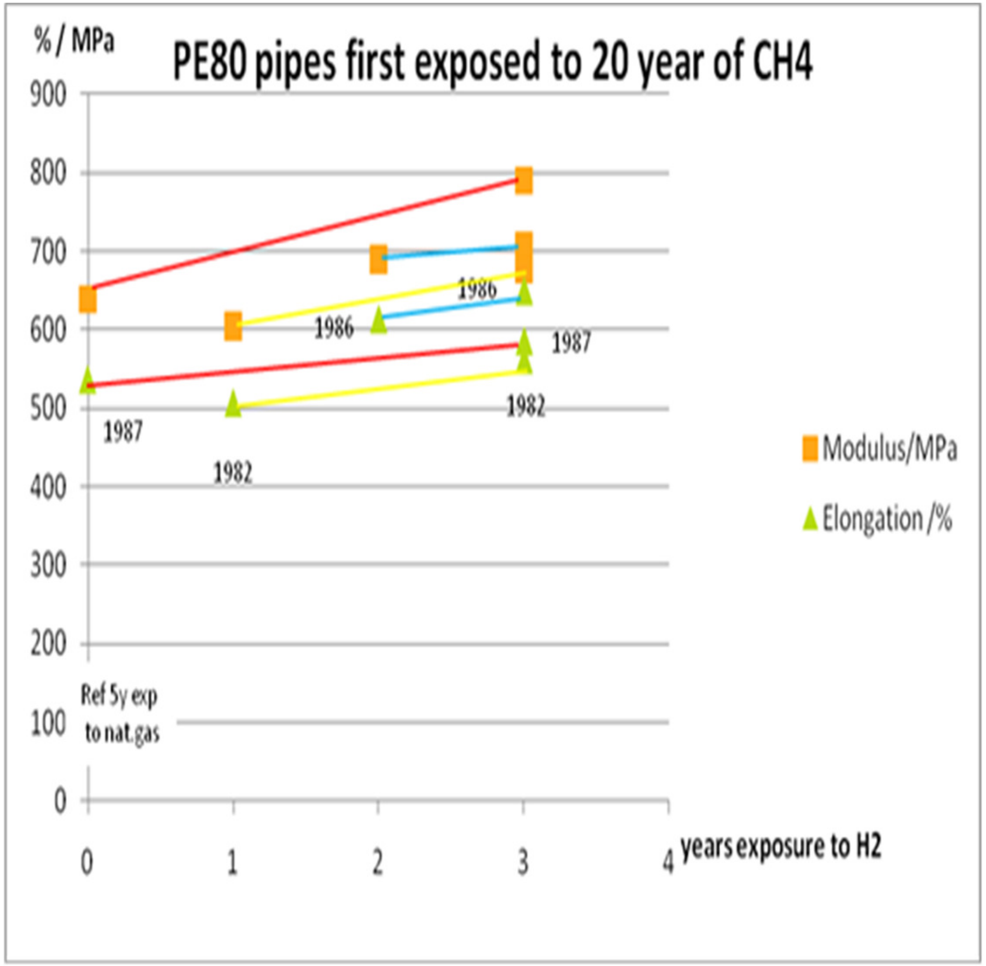
- Same conclusion as for PE80: H2 exposure results not in any rheological changes.

Determination of Oxidative power - consumption of antioxidants:



- There is no effect from hydrogen transport on the antioxidative power of the additivation of the polymer pipes, measured as oxygen induction Time (OIT). years before the hydrogen exposure. In the Gas pipe standard (EN 1555) an OIT of 20 minutes at 200 C is sufficient for a 50 year life time at 20 C.

Determination of changes in Tensile properties:



- No negative influence to tensile modulus or in elongation is found. There could be a possible increase of modulus with time however the change in comparison to the scatter in the test and the fact that samples of different manufacturing year has been used makes the observation clearly uncertain.
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Polymer testing Conclusion:

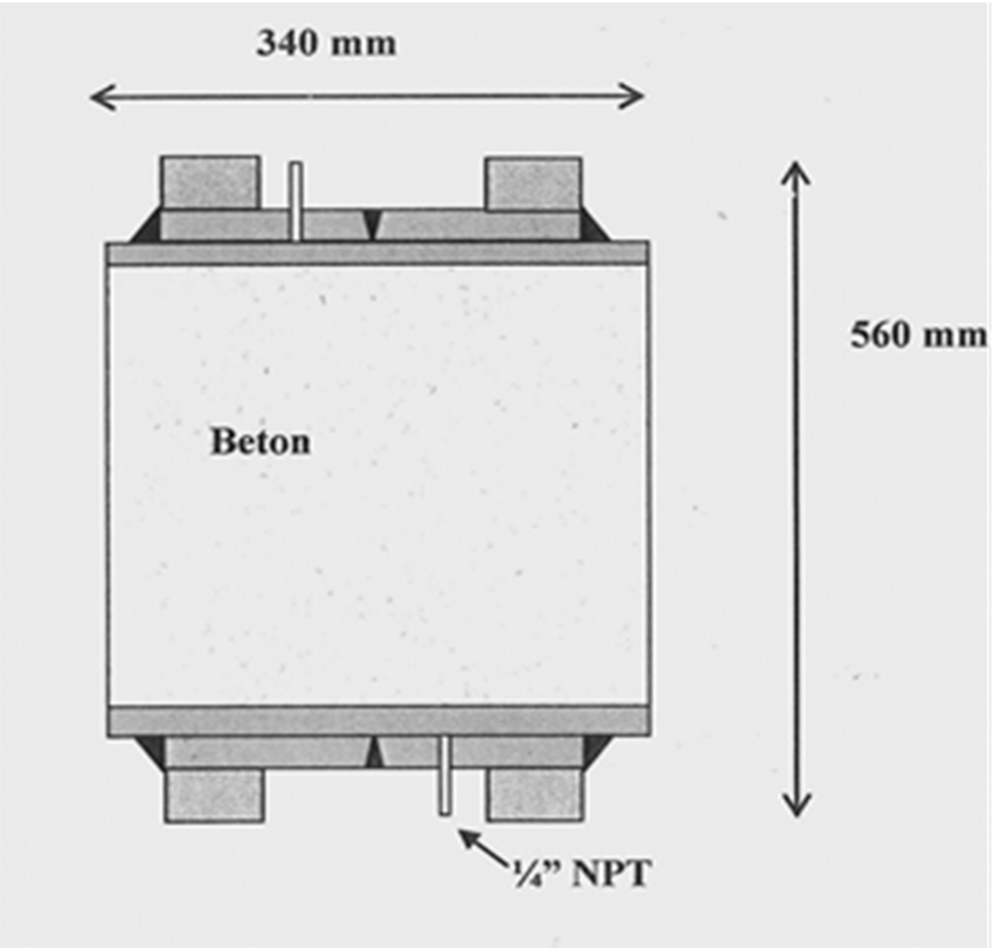
- In short: 4 years of continuous hydrogen exposure causes no influence on PE80 or PE100 natural gas pipes. In detail

- No influence on the basic structure on the pipes measured with rheology acc. ASTM 4440-95a.
- No influence on additivation/oxidative strength on the pipes measured with oxygen induction time (OIT) acc. EN 728
- No influence on the slow crack growth properties measured as CTL at 5 MPa/60 C acc. to ISO6252-1992 / ASTM1473 F.
- Uncertain influence on the pipes measured as elongation at break and tensile modulus ISO 527. **This is investigated in an on-going field test for another 5 years!**

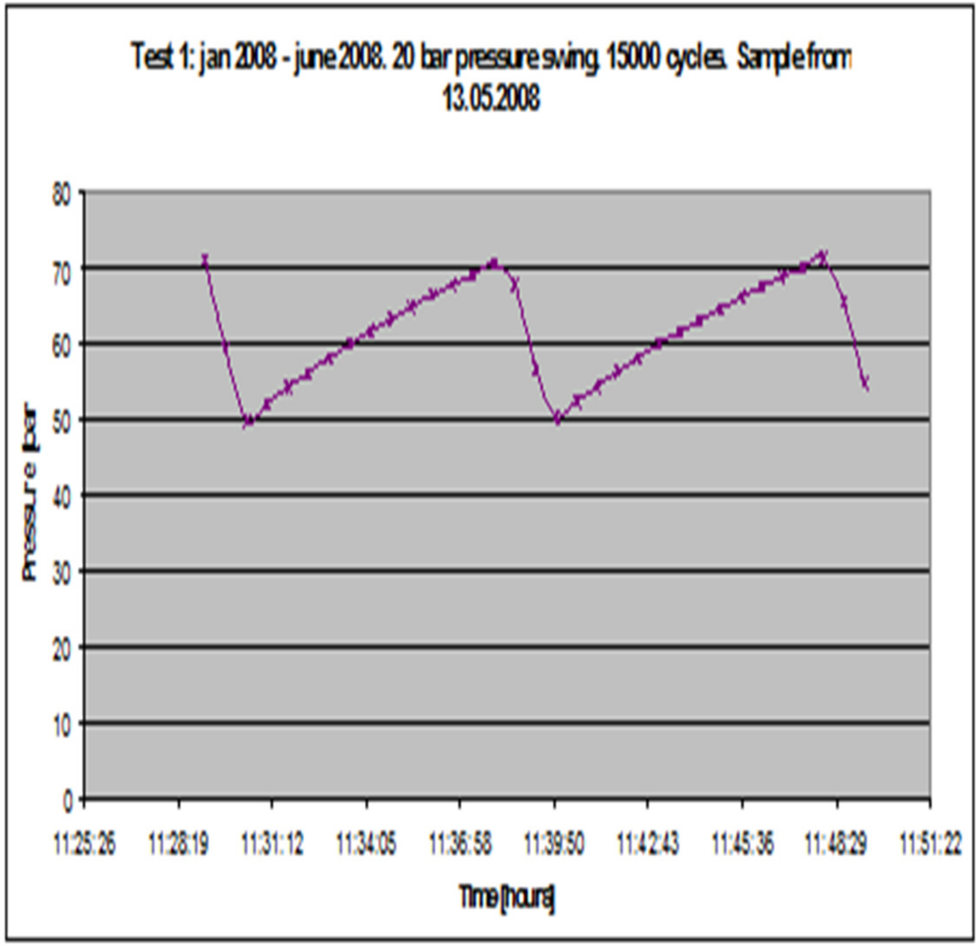
X70 steel natural gas transmission pipeline test and analysis:

- **Introduction and objectives**
- Most studies aiming to describe the fatigue limits of existing pipelines for hydrogen gas distribution has been based on fracture mechanics principle and it was found of less use to try to reproduce this work. Instead, it was decided to make **a series of full scale test exposing pipes to fluctuating pressures of hydrogen gas**.

- **The object of the steel pipe test:**
- Analyze the effect on fatigue life of existing natural gas transmission lines with hydrogen replacing natural gas. The test and analysis focused on the effect of hydrogen on fatigue cracking in pipeline girth welds.



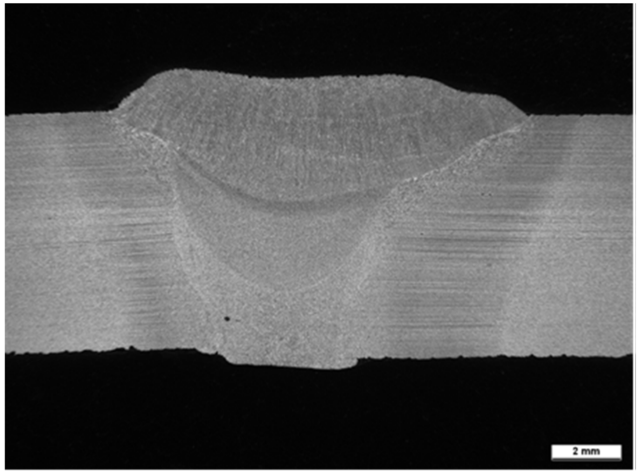
- Full scale tests was performed using cut-out API 5L X70 pipe sections 20 inch diameter by 7 mm WT retrieved after more than 20 years in the Danish natural gas transmission system. The pipe sections contained field girth weld (SMAW) made during the installation of the pipe line in eighties. The weld quality is assumed to repre-sent the Danish gas lines

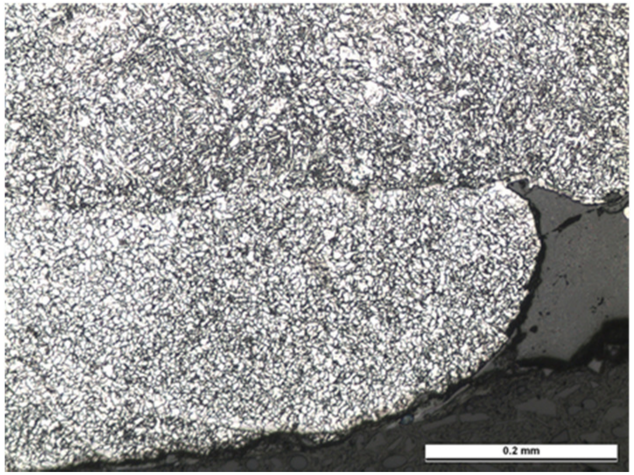


- The internal test environment consisted of 100% hydrogen gas at fluctuating pressures representing the daily peak to peak variation in the gas transmission line. The maximum pressure was 70 barg and the maximum pressure amplitude used was 30 bar.
- 2 test series were conducted with increasing pressure amplitude from 20 barg to 30 barg.

Results of steelpipe analysis

- The girth welds has been dissected and subjected to metallographic and MPI examination in addition to the ultrasonic testing in order to describe possible defects and defect growth in the weld zones.
- No indications of any fatique related fractures has been found.





Conclusion of Steel testing and analysis

- The dynamic testing equivalent of 80 years service with twice the maximal pressure variations found in the danish gas transmissionssystem (that is 2 x 15 bar equal to 40 to 70 bar in 30000 cycles) has not shown any defect growth.

- This provides some confidence for addition of hydrogen to the existing Danish gas transmission pipeline - provided it is free of significant weld defects.