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GAS DISTRIBUTION NETWORKS: ASSESSMENT OF THE LIFETIME OF AN INNOVATIVE SAFETY SYSTEM INSTALLED IN EXISTING SERVICE LINE

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1. Abstract

Between 2005 and 2009, the GDF SUEZ R&I Division developed a range of Excess Flow Valves (EFV) for existing service lines. This system is named DPBE. It can be installed from the gas box up to the tapping tee without excavations while the line remaining pressurized at 4 bars. The DPBE is a compact system including an elastomer seal lip and a set of stainless steel prongs to anchor it in a service line PE pipe.
This paper aims at assessing the lifetime of this innovative safety system. It focuses both on DPBE lifetime and its impact on PE pipe lifetime. The methodologies that have been developed are based on experiments and call for a wide range of tests: accelerated aging, internal hydrostatic pressure and mechanical tests.
These studies have shown that the DPBE is a reliable system which can be operated on distribution network up to 50 years corresponding to the GrDF requirement. So, the DPBE has been rolled out on the GrDF network since the end of 2009. To date, over 10,000 PE service lines in 20 (¾") and 32 mm (1 ¼") external diameters have been made safer using this innovative solution.

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2. Introduction

The protection of existing service lines is a safety issue for GrDF, the GDF SUEZ subsidiary in charge of gas distribution in France. Thus, between 2005 and 2009, the R&I Division developed a range of protection systems for existing service lines. The system is named DPBE. It is protected by seven patents exclusively owned by GDF SUEZ. In France, this technique can be used to improve the safety of service lines installed prior to 2000, which is the year that safety systems became mandatory on new service lines.

The system is an excess flow valve that can be installed from the gas box up to the tapping tee without excavations while the line remaining pressurized at 4 bar (60 Psi). Figure 1 shows the standard service line configuration and where the DPBE is installed.

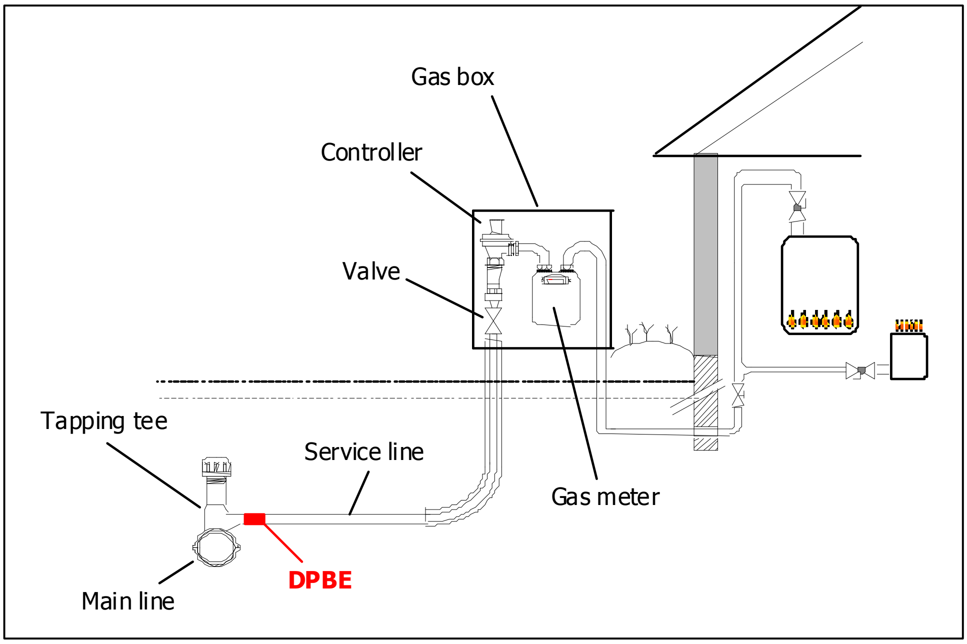

Figure 1: Standard GrDF service line configuration

To be installed in the service line, the DPBE is inserted in a sleeve with a first specially designed tool. Once in its sleeve, it can be inserted through the valve being in the gas box (see Figure 1) with a second specially designed tool. This tool enables to move this compact system up to the tapping tee and to eject it from its sleeve. When ejected from its sleeve, the DPBE is anchored to the inside of the pipe by stainless steel prongs that spread out and make contact with the inside of the pipe. The DPBE also includes an elastomer seal lip in Nitrile Butadiene Rubber (NBR) that seals the passage and ensures that the gas only passes through the system’s valve seat.

Figure 2 presents DPBE for 20 mm (¾") external diameters PE service lines:

Figure 2: DPBE for 20 mm (¾") external diameters PE service lines

Figure 3 presents DPBE for 32 mm (1 ¼") external diameters PE service lines:

Figure 3: DPBE for 32 mm (1 ¼") external diameters PE service lines

Figures 4 presents the DPBE for 20 mm once installed in the PE pipe:

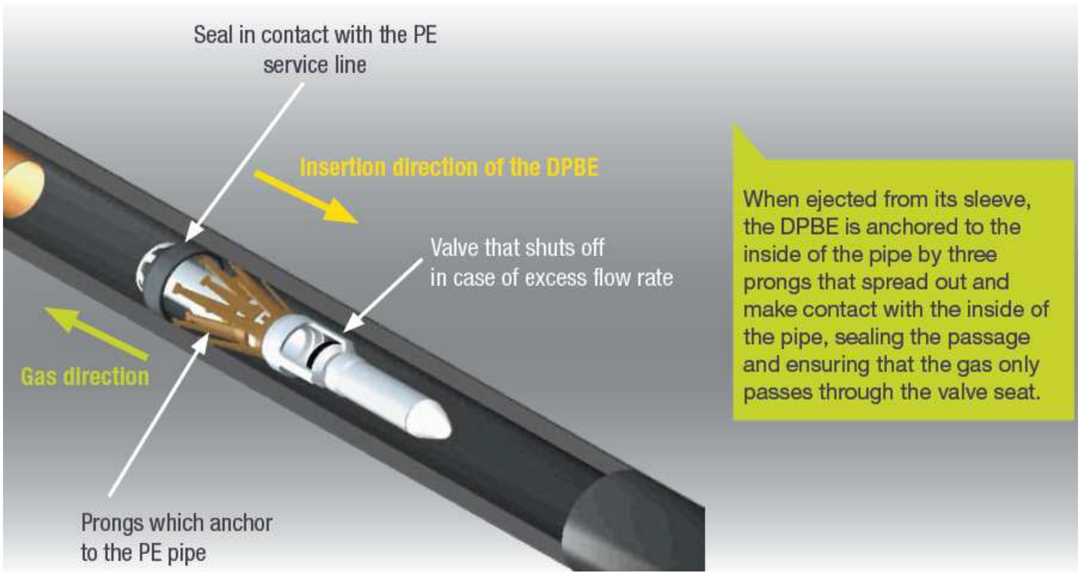

Figure 4: DPBE for 20 mm once installed in the service lines

Once installed close to the tapping tee, the system offers a guaranteed seal able to protect the service line on case of external attacks that can be a gas box catching fire or a damage during site works.

To be rolled out on the GrDF network, each new system must meet general technical requirements. One defined for PE distribution network operated at 4 bars consists in being able to be used up to 50 years. So, a complete lifetime assessment was carried out for the DPBE. It concerns both DPBE lifetime and its impact on PE pipe lifetime.

3. Methodology

3.1. Concerning the DPBE lifetime

In order to ensure that the seal lip can work during the entire use of the PE pipe, accelerated aging tests were carried out. A classical Arrhenius model was used to describe and characterize the long term elastomer behavior in the presence of natural gas. Thus, elastomer specimens were submitted to the action of natural gas at different temperatures (60, 70, 80, 90℃) that permitted to identify a time-temperature couple equivalent to an exposure of about 50 years at room temperature. This couple corresponds to 72 days at 90℃.
After having checked that they met the technical specifications defined for DPBE in terms of pressure drop, shutting and sealing, six specimens were maintained in an oven at 90℃ during 72 days. After having submitted to this accelerated aging condition, DPBE behavior was assessed following the same technical characteristics.

3.2. Concerning the DPBE impact on PE pipe lifetime

Three experimental approaches were used in parallel to assess the influence of the stainless steel prongs on PE pipe lifetime. In the field of gas research at GDF SUEZ, it was the first time that a system could interact directly with the inside of the pipe. Indeed, to anchor the system in the pipe, the prongs indent softly its inner wall and exert a local pressure on it due to their elastic behavior.

The first two approaches are based on internal hydrostatic pressure tests achieved in conditions defined by the EN ISO 1167-1 [1] and EN ISO 1167-2 [2] standards. All the tests were made at a temperature of 80℃ and a circumferential stress (i nduced by the pressure) of 4 MPa.
The first approach consisted in making tests on PE pipes containing DPBE. Indeed, to carry out some tests with DPBE in pipes enables to be in a conservative way despite the difficulties to analyze physical phenomena existing between steel and PE at 80℃.
The second approach consisted in making tests on PE pipes without DPBE but with calibrated indentations ranging from 0.1 to 1.5 mm.
For all these tests, witness specimens were chosen among the oldest PE resins either stored at GDF SUEZ R&D Division or fabricated on purpose and representative of PE currently laid on the GrDF network (ethylene-hexene and ethylene-butene PE80).
All the specimens have been maintained to the specified circumferential stress of 4 MPa until they fail.

The third approach consisted in making mechanical tests to assess the force exerted by one prong on the inner wall of the pipe in order to compare it to the force required to pierce the pipe wall. The test can be imaged as the bending of a cantilever beam with a load concentrated at its end. An experimental designed device was made especially for this aim (see Figure 5).

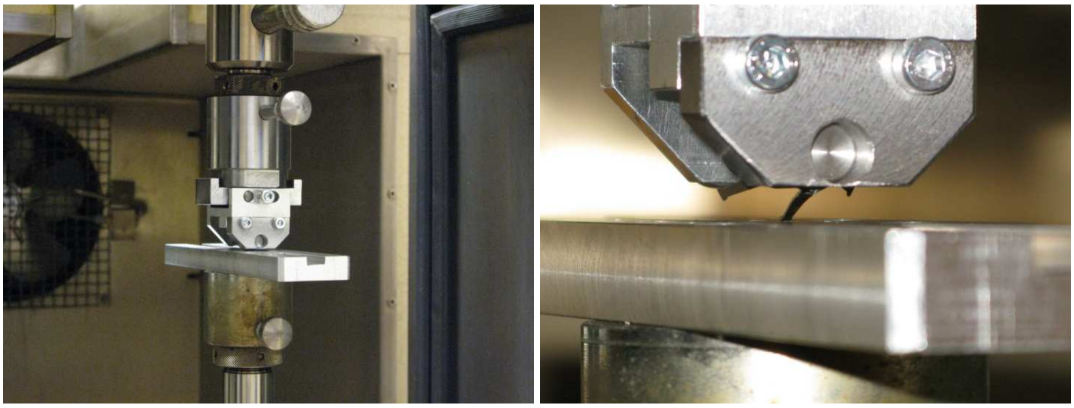

Figure 5: Experimental device made for testing the prongs

4. Results and discussion

4.1. Concerning the DPBE lifetime

The results showed that the DPBE for 20 mm external diameter meets the technical specifications even after 72 days at 90°C corresponding to about 50 years at room temperature. In particular, the leaking rate while the valve being shut off remains under the required value of 20 (n)l/h (in natural gas) excepted for one specimen for which the leaking rate is slightly higher than the specification but still acceptable.

Table 1 details the DPBE for 20 mm results before and after accelerated aging tests:

	Technical specifications required values (in l/h in gas)		Specimen number	Before accelerated aging tests values (in l/h in gas)		After accelerated aging tests values (in l/h in gas)	
	At 1 bar	At 4 bar		At 1 bar	At 4 bar	At 1 bar	At 4 bar
Sealing test	< 20 l/h	< 20 l/h	1	$< 3.10^{-2}$	$< 3.10^{-2}$	2.433	0.279
			2	$< 3.10^{-2}$	$< 3.10^{-2}$	2.103	0.277
			3	$< 3.10^{-2}$	$< 3.10^{-2}$	2.133	0.286
			4	$< 3.10^{-2}$	$< 3.10^{-2}$	1.246	0.263
			5	$< 3.10^{-2}$	9.067	64.586	0.287
			6	$< 3.10^{-2}$	0.289	1.642	0.289

Table 1: DPBE for 20 mm leaking rates before and after accelerated aging tests

In the same way, the results showed that the DPBE for 32 mm external diameter meets the technical specifications after having experienced similar conditions.

Table 2 details the DPBE for 32 mm results before and after accelerated aging tests.

	Technical specifications required values (in l/h in gas)		Specimen number	Before accelerated aging tests values (in l/h in gas)		After accelerated aging tests values (in l/h in gas)	
	At 1 bar	At 4 bar		At 1 bar	At 4 bar	At 1 bar	At 4 bar
Sealing test	< 20 l/h	< 20 l/h	1	4.933	3.734	2.843	6.562
			2	1.692	4.313	2.798	2.677
			3	0.298	2.723	1.955	3.687
			4	0.294	3.495	3.587	3.522
			5	0.287	0.277	6.257	3.377
			6	0.525	0.292	3.186	3.899

Table 2: DPBE for 32 mm leaking rates before and after accelerated aging tests

4.2. Concerning the DPBE impact on PE pipe lifetime

For the first two approaches, the duration of 1,000 hours commonly accepted as equivalent to 50 years at 20°C is far exceeded (see EN 1555-2 standard [3]).
About the first approach, the results show that the DPBE external diameter has no significant impact on the pipe PE lifetime. Indeed, tests are still ongoing and their durations reach more than 17,000 hours for the ethylene-hexene copolymer pipe with or without DPBE for 20 mm. It concerns three specimens in each case.
About the second approach, tests are also still ongoing and their durations reach more than 12,000 hours for the ethylene-butene copolymer pipe indented to 1.5 mm.

Figure 6 shows the duration of hydrostatic pressure test as a function of the indentation depth of the PE pipe:

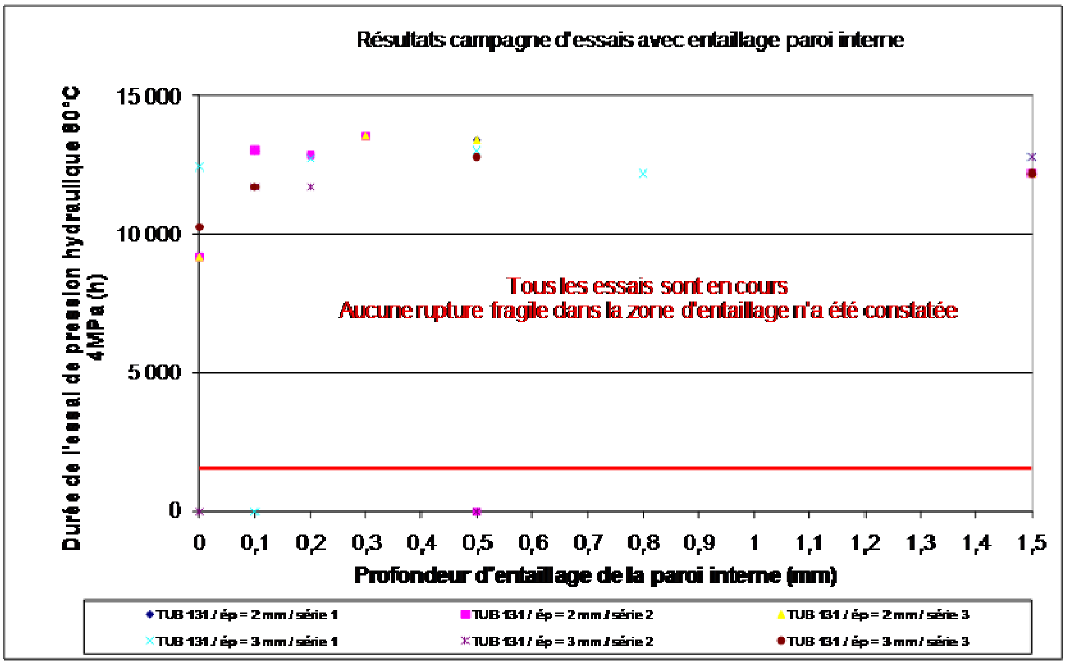

Figure 6: Duration of hydrostatic pressure test as a function of the indentation depth of the pipe

Similar results are observed with the DPBE for 32 mm external diameter for which all the tests are still ongoing.

About the third approach, the results showed that the force required to pierce the pipe is about ten times higher than the one exerted by a prong.

Firstly, concerning the DPBE for 20 mm, both the prongs geometry and positioning were examined. The possibility to create some scratches on the inner surface of the pipe whose orientation is perpendicular to the pipe axis was assessed.
So the analysis of laboratory specimens containing a DPBE two years after its installation confirmed a very small depth. Figure 7 shows the scratches generated by the DPBE.

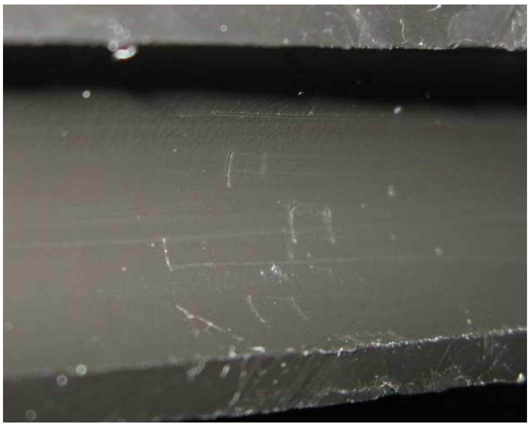

Figure 7: Scratches generated by the DPBE on a 20x2 mm pipe inner surface two years after its installation at 20°C

Then the geometry of such a scratch is known to have a far slighter mechanical impact on the pipe lifetime compared to the equivalent fault oriented along the pipe axis for the following reasons. Firstly the widest surface exposed to the stresses is perpendicular to the pipe axis for which the traction stress is negligible (centered fault on an infinitely long pressurized pipe) and secondly, the surface exposed to the hoop stress is extremely small. Consequently the internal pressure is supposed to have no significant effect on such a fault and the scratch is not likely to provoke a slow crack growth neither in the transverse direction nor in the longitudinal direction. The hydrostatic pressure tests in progress up to now on pipes with calibrated internal indentations confirm the poor impact of such faults on the 20x2 and 20x3 mm pipes (see the second approach presented above).

The mechanical test was done on a steel bar on the one hand and on a PE slice on the other hand. The PE slice was machined in the pipe wall with a final thickness of 4 mm. At purpose the PE was chosen among the oldest PE laid on the GrDF distribution network and belongs to the ethylene-butene PE63 family.

The results showed that the prong exerts a quasi elastic force not higher than ca. 11N when compressed to adapt to the 20 mm pipe internal diameter either with a 2 mm or a 3 mm wall thickness, taking into account of the tolerances during pipes fabrication. Moreover these results suggested that the behavior is quite the same when using either the steel sheet or the PE slice. Finally no scratch or indentation can be observed on the PE slice surface even after 10 compression cycles (see Figures 8 and 9).

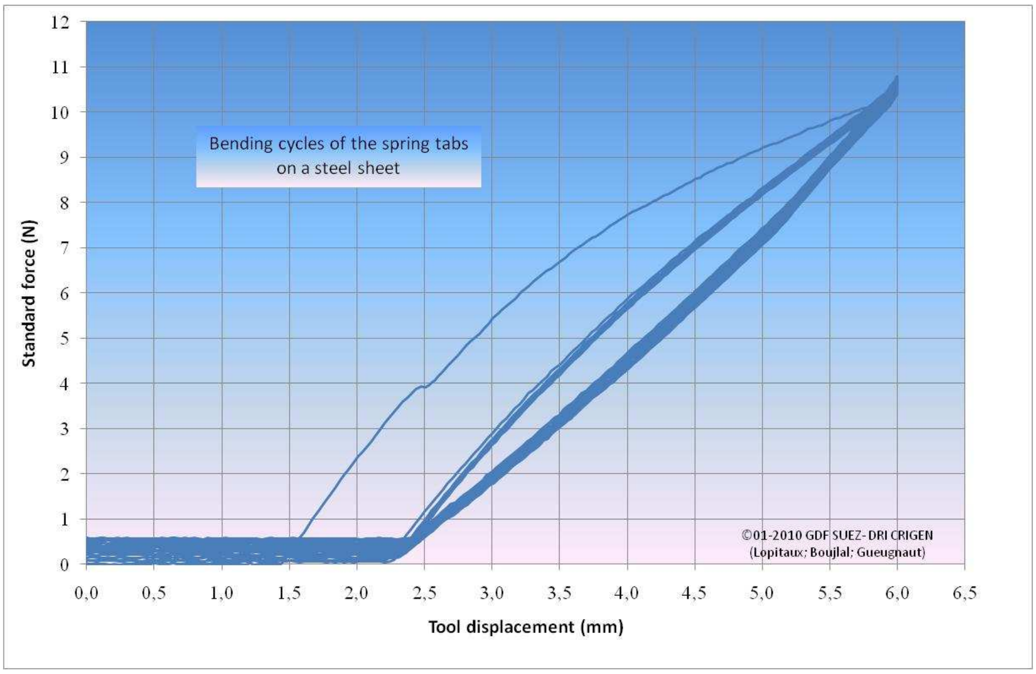

Figure 8: Force vs. Displacement during bending of the prong on a steel sheet

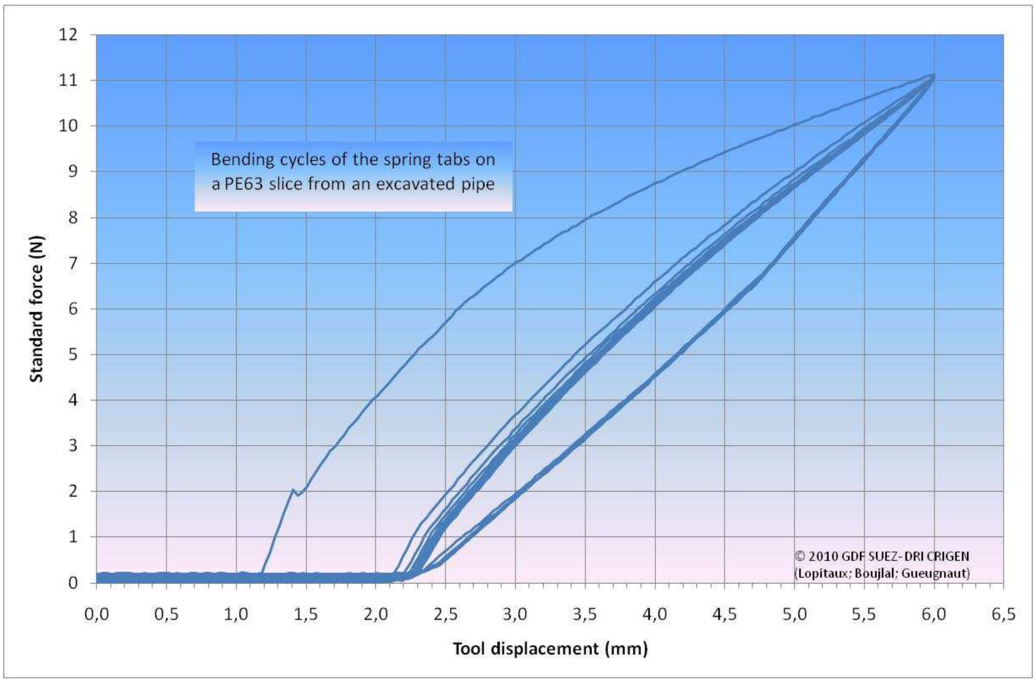

Figure 9: Force vs. Displacement during bending of the prong on a PE63 slice

After the first cycle, the prong did not totally recover indicating a permanent deformation. In addition, measuring the prongs crown before and after the 10 cycles showed after 24 hours a remaining bend of the prongs of the order of 0.8 mm to 1.2 mm (in diameter) that had disappeared after a period of 7 days.

Nevertheless it could be useful to check the possible persistence of this phenomenon in the actual conditions of a crown compressed inside a pipe with the more pregnant conditions regarding the dimensions.

The quasi elastic force exerted by the prong (ca. 11N) must be compared to the force necessary to indent or punch the pipe. For this purpose another specific experimental device had been designed in order to make indentations similar to those implemented on pipes in the hydrostatic pressure tests. This device was mounted on the traction-compression machine (see Figure 10). The indentation tests were carried out on the same ethylene-butene PE63 copolymer at 20°C.

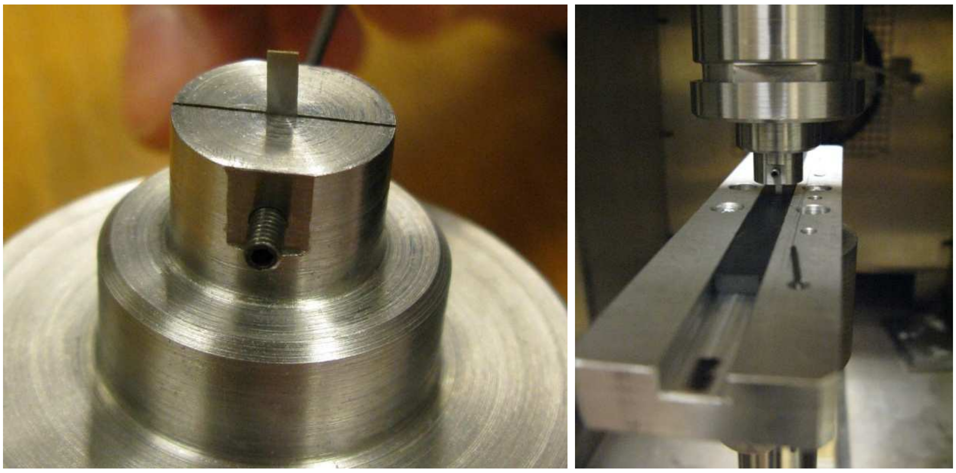

Figure 10: Experimental device for indentation testing on a PE63 slice

The force necessary to penetrate the PE63 slice at several given depths in the range 0.1 mm to 4 mm (through-wall complete perforation) was measured (see Figure 11).

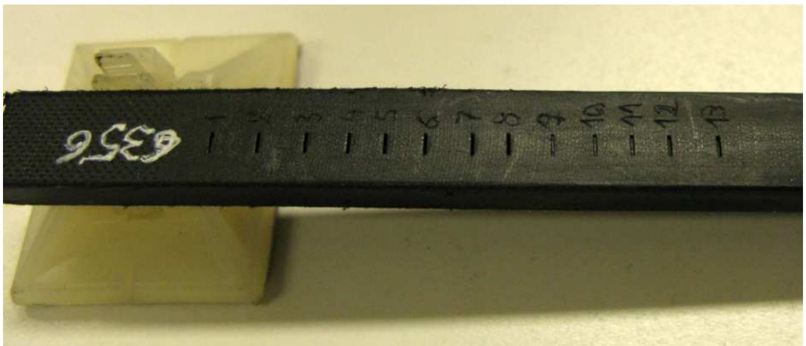

Figure 11: PE specimen with several given indentation depths in the range

Figure 12 shows the measured force as a function of the imposed displacement during the penetration of the tool in the PE slice.

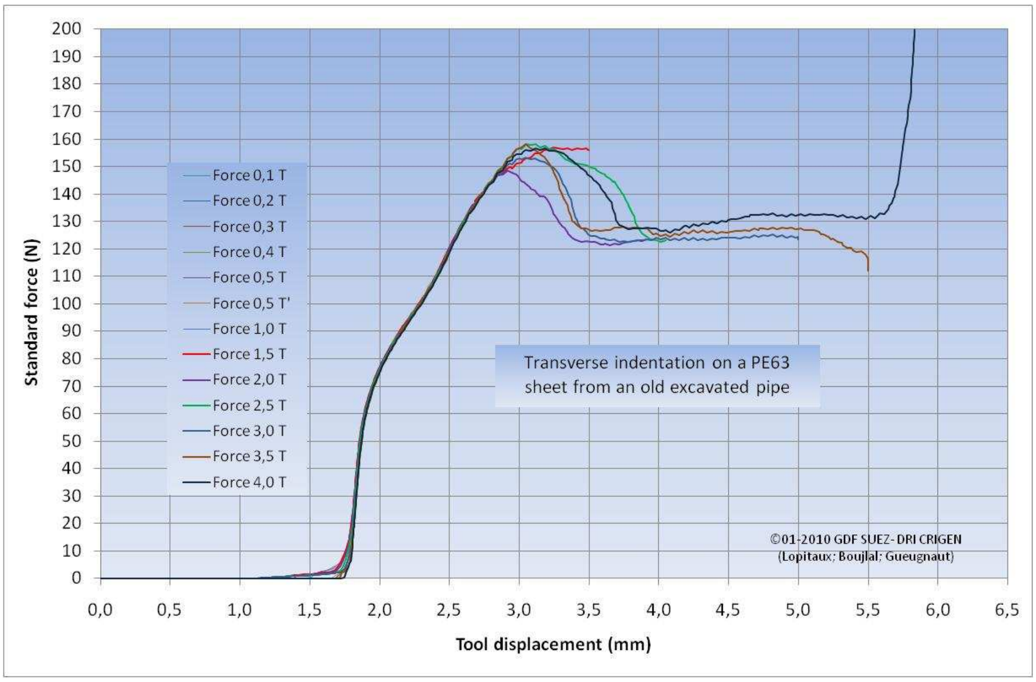

Figure 12: Force vs. Imposed displacement during penetration of the tool in the PE63 slice

The results showed that the force necessary to indent the pipe wall is in the range 80 to 160N (complete perforation). Consequently the force exerted by the prong is far lower than the force necessary to indent the pipe wall.

5. Conclusion

These studies have shown that DPBE is a lasting and reliable system which has no significant effect on the PE pipe lifetime. Thus, it can be operated on distribution network at 4 bars up to 50 years. It therefore meets the technical requirements of GrDF.
The DPBE has been rolled out on the GrDF network since the end of 2009. To date, over 10,000 PE service lines in 20 (¾") and 32 mm (1 ¼") external diameters have been made safer using this innovative solution. This deployment was made possible after having carried out all these detailed studies on the DPBE lifetime and its impact on PE pipe lifetime.
The product and its insertion tool are currently manufactured under license by two French companies.

6. References

[1] EN ISO 1167-1: Thermoplastics pipes, fittings and assemblies for the conveyance of fluids; Determination of the resistance to internal pressure; Part 1: General method.

[2] EN ISO 1167-2: Thermoplastics pipes, fittings and assemblies for the conveyance of fluids; Determination of the resistance to internal pressure; Part 2: Preparation of pipe test pieces

[3] EN 1555-2: Plastics piping systems for the supply of gaseous fuels; Polyethylene (PE); Part 2: Pipes

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