USER-FRIENDLY INSTALLATION OF A CROSSLINKABLE PE FOR HOT PRESSURIZED WATER

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To heat buildings and houses, a common source of heat with a large ‘district heating’ distribution system is used more and more. This system is both economic and ecological as it avoids the generation of heat by thousands of private heating systems. Such networks are currently made mainly with steel coated with PU foam layer and an external casing pipe in polyethylene. Steel pipes may be subject to corrosion under the combined action of water transported and temperature. New solutions are now investigated. One of these new materials is crosslinkable PEX, which is based on silane technology. By crosslinking the PEX pipes during operation, the installation and welding of pipes can be made as for standard PE pipes. This paper brings all the elements necessary to understand and take into account all the key points of such a network and its good use.

INTRODUCTION

So-called district heating systems or geothermal systems are used to transport hot water to consumers houses and provide heat and hot tap water through heat exchangers. They are mainly made with steel pipes and sometimes suffer from corrosion. In the worst cases, such steel pipes must be replaced every 3 years and can show leakages as high as 50%. Leakage comes mainly from mechanical joints.

In the in-house hot and cold water systems, metal pipes like copper are quickly replaced by new plastic solutions like PEX pipes. They are cheap, easy to install, they present no risk of corrosion, no leakage and a very long guaranteed lifetime.

These solutions can be extended to district heating systems. The main differences come from the size of the pipes which are much larger diameter for district heating and the pressure and temperature applied to the network. A good PEX material, fully characterized and with high level mechanical properties will be perfectly suitable. The only issue remaining is the joining of pipes. When crosslinked, PEX cannot be welded anymore.

To overcome this issue, the idea is to first install and weld the pipes and allow the hot water to fully crosslink the pipes during operation of the network. Will this influence properties of pipes ? Is it really feasible ? On a more general basis, what does it imply? All these questions will be addressed in this paper.

1) PROPERTIES OF AN IN-SITU CROSSLINKED NETWORK

In-situ crosslinking means crosslinking the pipes under pressure during operation of the network. This means that pipes will be first in a state where they have not reached their full properties. During this stage, temperature and pressure will be applied anyway as if the pipes were fully crosslinked. Under the action of water and temperature, full crosslinking will occur over several days or weeks.

A study (1) has been launched by BP Solvay Polyethylene in partnership with Gastec Technology, independent testing institute, Lögstör Ror, pipe producer from Denmark and EnergieNed, the Association of Energy Distribution companies in The Netherlands. The goal was to assess the feasibility of in-situ crosslinking and the effects on the final properties of pipes and also fused joints. The chosen material was ELTEX®TUX100, a silane PEX from the BP Solvay Polyethylene range.

1.1) GENERAL CONDITIONS APPLIED

The pressure and temperature operating conditions were chosen according to the needs of EnergieNed. Basically, the maximum pressure used is 4.5 bar and the temperature is 95°C for the winter period when houses need to be warmed up. In summer time, the temperature of the network is maintained at least at 70°C to avoid development of legionella bacteria in the consumer's heat exchanger. Typical pipe sizes chosen for this study are 32mm SDR11 and 110mm SDR11.

1.2) DIMENSIONAL CHANGES

Assessing dimensional changes is very important mainly for 2 reasons. First one is to avoid issues of connections. A small gap between a coupler and the pipe can lead to poor quality welding. The second reason is fatigue created by the temperature variations. In certain district heating systems, the network is not operated in a continuous flow which induces variations of temperature. Due to the higher coefficient of thermal expansion of PEX, expansion and shrinkage due to temperature variations will create stresses and cycling will result in fatigue. This item on fatigue will be dealt with later in this paper.

Diameter, length and wall thickness of pipes have been monitored before, during and after crosslinking the pipes by flowing hot water at 95°C inside without or with pressure to simulate a real district heating network.
Figure 1 below shows these dimensional changes for in-situ crosslinking performed at 95°C and both under 2 bar and 4.5 bar pressure in function of the gel content. All dimensional measurements are made at the same temperature, 23°C.

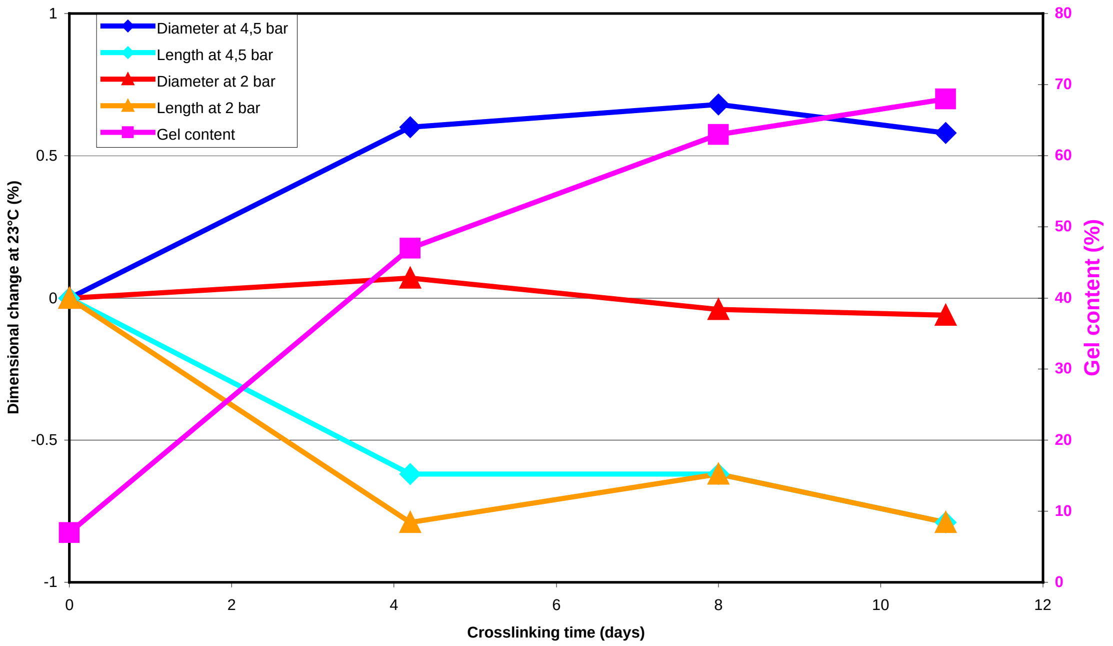

Figure 1 : Results of dimensional changes on ELTEX®TUX100 pipes of 110SDR11 when in-situ crosslinked at 95°C under 2 bar and 4.5 bar (Courtesy of Gastec Technology)

These dimensional changes are the combination of 2 contributions: crosslinking and stress relaxation, both being a shrinkage component. To decouple the 2 contributions, values obtained were compared to dimensional changes of a PE pipe annealed for some days in hot water and then cooled down to ambient temperature. In the case of the PE pipe, only stress relaxation exists.

Results obtained showed that decrease in length due to stress relaxation of the PE pipe is more than 0.5%. Compared to the values of the figure 1, it proves that the main part of the shrinkage is due to the stress relaxation in the pipe and not from crosslinking.

Concerning the rate of crosslinking of pressurized pipes, it seems not to be affected by the pressure inside the pipe. The final gel content of 71% obtained at 95°C has been reached in about 11 days. The model developed by BP Solvay Polyethylene predicted a value of 13 days to reach the same gel content, taking into consideration the thickness, the temperature and the fact that pipes were crosslinked only from inside.

1.3) PRESSURE TESTING

The next important step was to check that mechanical properties of pipes were not influenced by in-situ crosslinking. To do so, a stress level has been chosen from the regression curve to allow a failure time of around 1000 hours. At 6.1 MPa and 95°C, the failure time reported on the regression curve of ELTEX®TUX100 is 1050 hours.

Pipes of 110SDR11 and 32 SDR11 were in-situ crosslinked under the most severe conditions, meaning 95°C and 4.5 bar. The results were at least as good as those obtained in the regression curve as values obtained on 110mm SDR11 pipes were above 1050 hours and on 32mm SDR11, pipes were stopped after more than 1140 hours.

The conclusion to be drawn from this is that in-situ crosslinking pipes at 95°C under 4.5 bar does not affect the mechanical properties of pipes and so the expected lifetime of pipes.

1.4) BUTT-FUSED PIPES

Conditions of butt-fusion have been adapted from the ones of PE100 pipe according to a proprietary fusion method of Gastec named Xfuse®, to obtain good quality welds. Butt welded assemblies were crosslinked in-situ at 95°C and 4.5 bars.

To test the short-term weld quality, tensile testing at 150°C has been performed on punched samples. Draw rate was 10 mm/min. Testing at such a high temperature allows the quality of crosslinking to be assessed as only crosslinks will give a remaining strength to the material above the melting point. A series of samples punched from a non welded pipe crosslinked in a bath of water without pressure has been tested as a reference. The resulting average breaking stress is 0.92 MPa at 150°C.

To assess the short-term properties of the welds, the weld factor according to the DVS 2203-2 standard was applied. The ratio between the breaking stress of the welded sample and the breaking stress of the reference (0.92 MPa on non welded pipe) was calculated. The welding factor is expressed in %. The results are given in Table 1 below.

In-situ crosslinking	Breaking stress (MPa)	Elongation at break (mm)	Weld factor (%)	Failure location
95°C, 0 bar	0.66	79.3	72	Partially in the weld
	0.65	79.3	71	Outside the weld
	0.71	79.3	77	Inside the weld
	0.6	61.9	65	Outside the weld
Average	**0.66**	**75.0**	**71**	
95°C, 4.5 bar	0.87	110.5	95	Inside the weld
	0.91	113	99	Not failed (slipped from grip)
	0.92	121.4	100	Inside the weld
	0.96	130	105	Outside the weld
Average	**0.915**	**118.7**	**100**	

Table 1 : Results of tensile tests on samples from butt welded pipes at 150°C expressed in terms of welding factor compared to reference value on non welded pipe (0.92 MPa)

The results show that crosslinking under pressure gives even better results than without pressure. This result is probably due to the improvements of Xfuse® welding method.
To complete the testing of butt welds, constant load testing according to DVS 2203-4 was performed. It consists in cutting test bars from welded pipes and apply a tensile load while the sample is in a bath at 95°C containing 2% of Arkopal N100, a tensio-active that will speed up slow crack growth.

The idea of a welding factor has been taken again. In this case, a welding factor of 90% has been chosen, although DVS 2203-4 demands only 80% for PE100 and PE80 pipes. The stress value of the reference sample has been chosen to be 6.1 MPa which was the stress chosen to reach 1050 hours failure time in pressure testing. So, for butt welded samples, stress should be 90% of 6.1 MPa = 5.5 MPa and the time to failure should be at least 1050 hours. Samples taken from pipes crosslinked in-situ at 95°C both without pressure and at 4.5 bar were tested. Results are summarized in Table 2 below.

In-situ crosslinking	Testing time (hours)	Failure type
95°C, 0 bar	> 1244	No failure or crack
	> 1244	No failure or crack
	> 1244	No failure or crack
95°C, 4.5 bar	> 1409	No failure or crack
	> 1409	No failure or crack
	> 1409	No failure or crack

Table 2 : Constant load testing on samples taken from butt welded pipes at 95°C and 5.5 MPa (= 90% of 6.1 MPa).

Here again no failure occurred after more than 1200 hours proving first that welding was of a high quality and also that in-situ curing is not affecting this quality. According to the results obtained from these 2 types of tests, the conclusion is clear that in-situ crosslinking under pressure of a pipe jointed by butt-fusion does not affect the quality nor the mechanical properties of the joints.

1.5) ELECTRO-FUSION WELDING

Electro-fusion is not only an alternative to butt welding for medium size pipes but it is also a need for small diameter pipes. It allows also to make branch connections from the main network, for example to connect a new house or extend the network.

Until now, the need for crosslinkable PEX fittings was not very important for plumbing applications as every part of the network is crosslinked before installation. Also many couplers in copper, for example, exist and are cheap and easy to install and these are not exposed to high temperatures. However for district heating, pipes are usually of a larger size so that metallic fittings are no more cheap or easy to produce and are not the best solution as it is a pressurized network. PE100 fittings are not suitable due to the high temperature of use.

ELTEX®TUX100 has been used for both pipe and fittings, injection trials had already been performed by most important fittings producers in Europe with very good results. Mechanical properties and jointing properties have already been tested in previous studies commissioned by BP Solvay Polyethylene to Gastec Technology (reports available on request to the author). Such electro-fusion couplers were used in this project, produced by Georg Fischer Wavin Ltd. The dimension used was 32 mm SDR11. They were produced in 2 separated parts with natural resin for the main body and orange pigmented resin for the sealing fusion layer.

The same in-situ crosslinking was applied as for the other phases of the study. Two types of connections were made: non crosslinked electro-fusion couplers welded on non crosslinked pipes and non crosslinked electro-fusion couplers welded on crosslinked pipes.

An important point is of course that electro-fusion couplers must not be crosslinked to allow the coupler fusion zone to melt and form the adhesion with the pipe. Welding couplers on to crosslinked pipes has proved to be feasible with good quality and mechanical properties in the past. In all the cases, the whole assembly was then crosslinked at 95°C without pressure to finish crosslinking of the coupler (always by flowing hot water inside of the pipe).

To test assemblies, once again tensile testing at 150°C has been performed at 25 mm/min. The joints will fail in this test, but failure is not allowed at the weld plane, only in the coupler or in the pipe. Figure 2 shows a picture of the failure in the metal wire plane in the case of a coupler welded to a non crosslinked pipe. The weld plane (where the orange layer and the lower white part meet) shows very good adhesion.

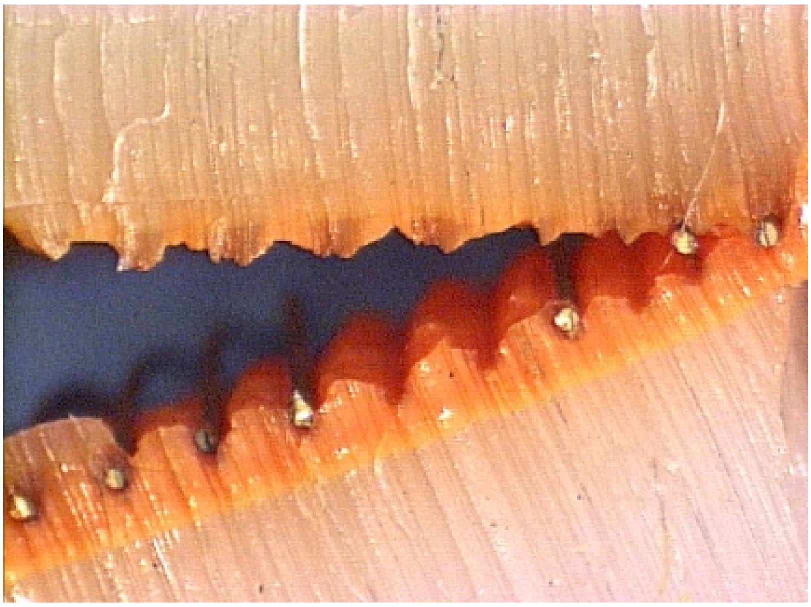

Figure 2 : Picture of failure in the wire area after tensile testing at 150°C of fusion between coupler (top) and non crosslinked pipe (bottom) (Courtesy of Gastec Technology)

Results obtained by tensile testing on welds with couplers both on non crosslinked and crosslinked pipes are given in Table 3. After welding, these couplers were crosslinked in-situ with water at 95°C without pressure.

Non crosslinked coupler fused on :	Failure type
Non crosslinked pipe	At the heating wires
Non crosslinked pipe	At the heating wires
Non crosslinked pipe	At the heating wires
Crosslinked pipe	During heating to 150 °C
Crosslinked pipe	During heating to 150 °C
Crosslinked pipe	During heating to 150 °C

Table 3 : Results of tensile testing at 150°C on assemblies made of non crosslinked couplers with non crosslinked pipes and crosslinked pipes.

The results obtained on joints made with non crosslinked pipe are good, while those on crosslinked pipes are very poor as the joint failed before loading. This clearly means that the joint was not cohesive but adhesive. The only way to explain this is that couplers were at least partially crosslinked and not able to really melt at the interface. Gel content measurements were made afterwards on these couplers and showed gel contents of around 45% which is far too high for fusion. The reason is that the electro-fusion on non crosslinked pipes has been made quickly after receiving the fittings so that they were really not crosslinked. On the other hand, welding and testing of electro-fusion on crosslinked pipes took place several months after that. The packaging that should normally protect the fittings from crosslinking had some defects allowing humid air to penetrate. In parallel to this study, another work has been launched in Germany and BP Solvay Polyethylene participates again. Some long term welding tests are currently performed by Hessel GmbH on welding assemblies made of crosslinkable PEX fittings welding on various types of pipes : PE100, PEX b crosslinked and PEX a. The results are very good up to now and confirm that the problems we had in this project with Gastec is only a logistic problem. Results of this German study are not yet published but should be available in several months.

Peel tests at 95°C and at 150°C on electro-fused assemblies are in progress. New welded assemblies for tensile testing at 150°C are being made to complete the above data.

1.6) CONCLUSIONS

As a general conclusion, we can say that all tests showed that it is possible to install, weld and then in-situ crosslink crosslinkable PEX pipes for a district heating network. Even with the most difficult conditions applied (95°C and 4.5 bar), no decrease in the properties was experienced. Also weld quality remains unaffected by the pressurization during crosslinking.

Now that the mechanical properties have been checked and the feasibility is assured, more practical questions are addressed in the second part of this paper.

2) DESIGNING THE NETWORK AND OTHER PRACTICAL QUESTIONS

On top of assessing the feasibility of in-situ crosslinking with a crosslinkable PEX, it is necessary to discuss more practical points linked to a district heating network. For example, while this pipe is the medium carrier, a PU foam layer will play an insulating role and a casing pipe will protect this layer. What will be the interaction with the PU foam in terms of properties? On a more general basis, what about temperature extremes due to malfunction of the network and finally, compared to steel pipes, what are the advantages and disadvantages of crosslinkable PEX? Answers given here are mainly taken out from a Technical File edited by BP Solvay Polyethylene (2).

2.1) DESIGN AND LIFETIME EXPECTANCY

To design such a pipe, a full characterization of the material is of course needed first. Such pipes do not only work at high temperature but also under pressure.

The material use, ELTEX®TUX100, is fully characterized. The approach used to classify the material has been chosen so that a full regression curve has been generated in the same way as for HDPE. For HDPE pipe applications, 50 years is usually the design lifetime. In district heating applications, a lifetime expectancy of 20 years is realistic when compared to replacement required on steel pipes due to corrosion. On this basis, 80°C will be the limit for 20 years for design purposes. To note that this depends on the country because each district heating company has its own way of working. So, each case must be considered separately.

This value is of course based on the rules that apply to PE pipes where the maximum extrapolation factor of 100 is used for a temperature difference between tested samples and design temperature of more than 40°C in accordance with ISO 9080.

In the particular case where the network will work at variable temperatures over its service life, the Miner's rule given in ISO 13760 allows to determine if a higher safety coefficient must be applied. The idea is first to estimate the time period during which the network will work at a higher temperature. This is of course an estimate and time and temperature should be rounded up to the highest value to be on the safe side. When various conditions have been identified, each contribution is added and the maximum allowed stress can be calculated as well as the SDR.

As pointed out in the first part of this paper, variations of temperature could create a phenomenon of fatigue due to thermal cycling. Figure 3 shows a result of fatigue testing at 23°Cobtained on a plate of ELTEX®TUX100 in a 3 points flexion test under an alternate deformation of 3.5%. Failure occurs after 79,200 cycles.

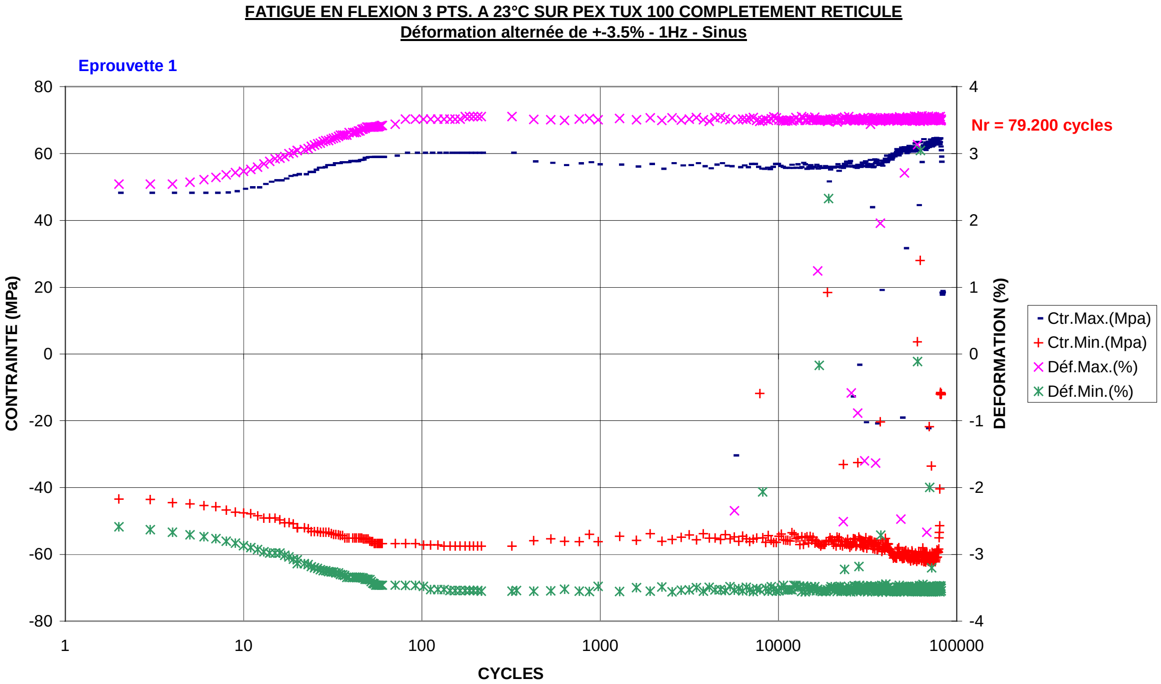

Figure 3: Fatigue of ELTEX®TUX100 resin in 3 points flexion method at alternate deformation of 3.5% at 23 °C.

To compare to what could be observed on a real network, we can take the worst case. We can assume that the network operates at 100°C and is shut down every day so that temperature will go down to 20°C and go up the next day to 100°C. This means 365 times per year and 18,250 times on a 50 years basis. Assuming also that the network is mechanically fixed at regular lengths so that all the stresses have to be accommodated by the pipes, then the deformation will be created by the dilatation following the formula $\Delta\varepsilon = \alpha \times \Delta T$, α being the coefficient of linear thermal expansion which is 180 µm/(m.°C) for ELTEX®TUX100.

At ΔT = 80 °C we obtain 1.44% deformation. So, 18,250 cycles at 1.44% deformation has to be compared to 79,200 cycles at 2*3.5%. The fatigue testing was performed at 23°C and this makes it difficult to compare directly to what can happen in the network but if we consider that PEX resin will be more elastic at high temperature, it means also that relaxation of stresses should be more efficient and problem of fatigue should not appear..

2.2) COMPARISON WITH STEEL PIPES

The use of PEX pipe totally eliminates the risk of corrosion, a serious issue with steel pipe in this application leading to short lifetimes and premature failure. However there are other advantages of the PEX system as discussed below. To have a global overview of a district heating system made with PEX, the best way is to compare with steel and take into account all the elements, including the PU foam layer. Main questions that should be addressed are: what are the stresses on the PU foam due to dilatation of PEX at high temperature? Is there a significant difference of weight? Is it possible to reduce the PU foam layer?

Considering thermal expansion, PEX has a higher coefficient of thermal expansion (180 µm/(m.°C)) than steel (more or less 15 µm/(m.°C) depending on steel type) and also than PU foam (100 µm/(m.°C) depending on PU foam used).

As PU foam is bonded to the carrier pipe and its mechanical resistance is much lower than steel or PEX, PU foam will expand or shrink following the carrier pipe. If the difference is too large, there is a risk to destroy the PU foam layer. We can directly compare coefficients of thermal expansion of PU foam and PEX and steel respectively and look at the differences obtained to have an idea of the deformation that will be induced. In the case of the steel pipe, we obtain a difference of 85 µm/(m.°C) and in the case of PEX, we obtain 80 µm/(m.°C). Considering that the coefficient of thermal expansion of PU foam and steel are approximate, we can consider that deformation in both cases will be more or less the same and a PEX pipe will not create more stresses in the PU foam layer than a steel pipe due to thermal expansion. The thermal expansion is not instantaneous because of the low thermal conductivity of plastics, therefore relaxation will occur and the actually stresses will be significantly less than the theoretical calculation while steel pipes do not relax any stress. In conclusion there is no risk of degradation of PU foam due to expansion of the PEX pipe.

Comparing the weight of pipes made of steel and pipes made of PEX, the advantage goes to PEX. Table 4 below summarizes some comparisons of thickness and weights of pipes both in steel and PEX. The density used for steel is an average value of 7 700 kg/m^3 and the values of thickness for steel pipe are taken from standards while the thickness of PEX pipe is calculated (all these dimensions do not take into account the PU foam layer nor the jacketing pipe.

Diameter (mm)	Thickness of steel pipe (mm)	Weight of steel pipe (kg/m)	Thickness of ELTEX®TUX100 pipe (mm)	Weight of ELTEX®TUX100 pipe (kg/m)
50	3.5	3.94	2.74	0.39
100	4.5	10.40	5.49	1.56
200	6.5	30.42	10.98	6.22
300	6.5	46.15	16.46	14.00

Table 4 : Pipe thickness and weight in function of pipe size for steel pipe and ELTEX®TUX100

Why is the 50mm PEX pipe thinner than steel? On top of the lightness of PEX pipes which allows ease of installation, flexibility is another strength of PEX pipes over steel pipes. The flexibility allows also easier storage and installation of pipes.

A last point is to check if the PU foam layer thickness could be reduced. This means that we have to check if PEX is a better insulating material than steel. Heat flow can be calculated taking into consideration thermal conductivity of materials, thickness of pipes and temperatures. The calculation will not be developed in this paper. Full calculation and explanations can be obtained on demand from the author. Results are given in Table 5.

Diameter (mm)	Δl_{steel} (mm)	Δl_{TUX} (mm)	Thickness of PU foam layer for steel pipe (mm)	$q_{steel+PU}$ (W/m^2)	q_{TUX+PU} (W/m^2)	Thickness of PU foam layer for TUX pipe calculated (mm)
50	3.5	2.74	60	33.33	33.24	59.83
100	4.5	5.49	80	25.00	24.89	79.66
200	6.5	10.98	100	20.00	19.86	99.32
300	6.5	16.46	120	16.67	16.53	118.97

Table 5: Heat flow through pipe and PU foam for both steel and PEX pipes and thickness

Columns named $q_{steel+PU}$ and q_{TUX+PU} give the radial heat flow in the case of a steel pipe coated with PU foam and in the case of PEX pipe coated with PU foam. The difference is very low. The calculated thickness of PU foam that can be used in the case of a pipe of PEX is given in last column. For each pipe size, the gain in PU foam thickness is less than 1 mm compared to what is obtained with a steel pipe.

Despite the lower thermal conductivity of PEX over steel, it is not sufficient to significantly reduce the PU layer thickness. The thickness of PEX is not sufficient to really act as an insulating layer. It is clearly not enough to justify a real advantage and reduce PU foam layer thickness.

CONCLUSIONS

PEX pipe is an excellent solution to replace steel in pressurized hot water networks if pressure and temperature are not too high and as long as the PEX material chosen is fully characterized to allow a safe design.

Among the advantages, we can highlight lightweight and flexibility of PEX pipe that will allow easy and cheap installation, in-situ crosslinking will allow to weld as standard PE and above all absence of corrosion leading to a perfectly leak free system will allow operation of the network without cleaning, protecting or frequent replacement of parts of it.

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1. Frans Scholten, Gastec Technology B.V., *Crosslinkable PEXb pipes and fittings for district heating systems draft report*
2. Paul Rugraff, BP Solvay Polyethylene, *ELTEX®TUX100 in District Heating applications*