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Opportunities for Plastics in Flexible Indoor Gas Pipe Systems

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ABSTRACT

Worldwide more and more buildings are connected to natural gas. Until recently the gas within the building was exclusively distributed through metal pipe systems, such as straight copper pipes, soldered together and straight steel pipes, screwed together.
About six years ago some pilot projects with PEX (crosslinked polyethylene) piping systems in domestic buildings were started in the Netherlands. These projects are still in operation and no problems have occurred up to this moment. Subsequently other projects followed and nowadays the use of plastic (and multilayer) pipes in The Netherlands is common indoor installation practice.
In this paper the suitability of PEX, PEX/Al/PEX and PE/Al/PE pipe systems for indoor gas installations with respect to technological aspects is discussed in more detail. Next to the technological suitability, the suitability of these systems also depends on other aspects, such as safety and economical aspects. These items are addressed as well.
When it comes to the technological suitability of flexible pipe systems containing plastic, these can be divided into physical, chemical and mechanical aspects. The systems made of PEX, PEX/Al/PEX and PE/Al/PE are all suitable with respect to these aspects, as far as the system requirements are met. In The Netherlands these pipe systems have to meet the requirements written down in the relevant GASTEC QA Approval Requirements.
A very important aspect to cover is the resistance against odorant permeation.
Summarised, the following conclusions can be drawn from the results of the extensive research programme on the permeation of odorant, carried out by Gastec:

- In the case of multilayer pipes consisting of PEX-aluminium-PEX and PE-aluminium-PE the permeation of odorant through the pipe wall is zero. Pipe systems made of these pipes are therefore suited for use in indoor gas installations, as far as the resistance to odorant permeation concerns.
- In the case of PEX pipes containing an EvOH layer, present in or as a coating on the outside or inside of the pipe, the permeation of odorant through the pipe wall is negligible. Pipe systems made of these pipes are therefore suited for use in indoor gas installations, as far as the resistance to odorant permeation concerns.

The permeation of odorant through pipes made of PEXa, PEXb or PEXc, without EvOH layer, show an inadmissible degree of permeation of odorant, when installed in a casing pipe (e.g. corrugated PE pipe). Since the regulations for installation of PEX pipes for indoor gas installations prescribe the use of such casing pipes in certain situations, it is strongly recommended that PEX pipes without EvOH layer are not used for indoor gas installations.

The safety of a flexible plastic indoor gas piping systems can be approached in different ways. One can build in extra safety devices, such as excess flow valves and thermal shut off valves, or one can install the system into the walls and floors, thus providing sufficient resistance against fire. The allowed options have to be described in the national installation regulations.

The use of plastics in flexible indoor gas piping systems can reduce the total installation costs compared to traditional metal piping systems. The total reduction is strongly dependent on the layout of the pipework system as prescribed in the national installation regulations. The average reduction that can be achieved in a normal gas installation is about 30%. What opportunities exist for flexible plastic indoor gas pipe systems in the near future?

A lot will depend on the ease of acceptance of these systems in different countries over the world. Next to the Netherlands also Germany allows the installation of multilayer pipe systems for gas indoors. Some other countries in Europe and other parts of the world are considering the application of flexible indoor gas pipe systems now as well.

A final, very new development is to introduce plastic fittings to make the mechanical connection, instead of metal fittings. If the results turn out to be satisfactory, it is possible to deliver a pipe system for indoor gas distribution which consists (almost) completely out of plastic. Who would have thought of that five years ago?

INTRODUCTION

Worldwide more and more buildings are connected to natural gas. Until recently the gas within the building was exclusively distributed through metal pipe systems, such as straight copper pipes, soldered together and straight steel pipes, screwed together. However some years ago, Gastec started to study the possibilities for alternative pipe systems to be used for indoor gas pipe systems.

Almost twenty years ago the first project with plastic pipes in houses was established. In New Zealand a number of houses were provided with plastic gas pipes made from Nylon (PA11), connected with push-in fittings. Because the gas pressure was relatively high (350 mbar), very small diameters of pipes were used. Some years later the installation of this kind of pipes was stopped. Rodent attack was given as the unofficial reason.

About six years ago some pilot projects with PEX (crosslinked polyethylene) piping systems in domestic buildings were started in the Netherlands. These projects are still in operation and no problems have occurred up to this moment. Subsequently other projects followed and nowadays the use of plastic pipes in The Netherlands is common indoor installation practice.

Meanwhile the installation of multilayer pipes (PEX/Al/PEX or PE/Al/PE) and corrugated stainless steel (CSST) pipe systems is also allowed inside buildings.

Until now the Netherlands is the only country worldwide where a full package of system certification procedures (GASTEC QA requirements and Quality Mark,[1-5] regulations for installation[6] and training programmes for installers is available for flexible indoor gas pipe systems, containing plastic.

However, other countries now seem to follow rapidly. In Europe flexible indoor gas pipe systems containing plastic are also allowed and used on a small scale in Switzerland (multilayer pipe systems made of PEX/Al/PEX). Last year also a large pilot project started with multilayer pipes in Solingen in Germany. Meanwhile the German certification body, DVGW, has launched the product requirements for multilayer pipe systems in Germany. Finally a large subsidised European project has started in which big end users and manufacturers of flexible indoor pipe systems are studying the application of these systems.

Flexible indoor gas pipe systems have some considerable advantages, such as a high flexibility, higher degree of user-friendliness and a fast installation procedure.

Furthermore, similar pipe systems are already being used in still growing amounts for potable water distribution, central heating and floor heating inside buildings. For an installer it would be advantageous in different respects (logistical, economical etc.) if such pipe systems can also be used for gas.

In this paper the suitability of PEX, PEX/Al/PEX and PE/Al/PE pipe systems for indoor gas installations with respect to technological aspects is discussed in more detail. Next to the technological suitability, the suitability of these systems also depends on other aspects, such as safety and economical aspects. These items will also be addressed.

TECHNOLOGICAL SUITABILITY AND REQUIREMENTS

When it comes to the technological suitability of flexible pipe systems containing plastic, these can be divided into physical, chemical and mechanical aspects.

Physical and Chemical Aspects

Considering the physical and chemical aspects of PEX, PEX/Al/PEX and PE/Al/PE with respect to the use for gas indoor piping systems, it is very important to find the answer to the following questions:

1. Will the pipe system be gas tight?
2. Will the pipe system be resistant to gas components?
3. Will the pipe system be resistant to permeation of odorant?

The first question is a logical one to ask. PEX is getting more and more popular for use for gas outdoors. Within the pipe branch it is generally known that the permeation of gas (methane) through a PEX pipe wall is not significantly different from permeation through a PE pipe wall. All polymers show some permeation of methane, but this is to an extent that it can never cause a dangerous situation, either externally or in buildings, as long as the installation procedures for these kind of pipe systems are followed strictly. In The Netherlands it is permitted to enter the building with a PE service line, as a branch of the main gas pipe in the street, through the wall up to the gas meter, which in The Netherlands is installed inside the building. The only requirement is that the part of the PE service line inside the building is protected against external influences, such as mechanical third party damage or thermal damage (for example caused by a powerful light, used during the building stage).

The gas tightness of the joint between pipe and fitting will of course be guaranteed as well. For numerous types of mechanical connection available on the market, this can be achieved quite easily by carrying out similar tests as those already known and successfully applied to other mechanical jointing systems in the gas distribution field.

The second question about the resistance to gas components (condensate) is also important to answer. In certain situations it is still possible that gas condensate can reach as far as gas lines inside buildings. If the gas condensate stays at the bottom of a plastic pipe long enough, it could cause damage to it. All plastic pipe materials being used to distribute natural gas have to pass the internationally accepted standard test to determine the resistance against gas condensate. This test and the requirement are described in ISO 1167. PE80 and PE100 pipe materials normally pass this test without a problem.

For different brands of PEX pipes, Gastec has determined the resistance to gas components in accordance with ISO 1167. The tests were carried out on pipes with a 20 mm diameter. The synthetic condensate used for this test is a mixture of 50% (m/m) n-decane and 50% 1, 3, 5-trimethylbenzene. Prior to the test, every pipe was filled with the liquid and conditioned for 24 h at 80 ± 2ºC. After conditioning, the pipes were tested at 2 MPa with the synthetic condensate in the pipe and with water on the outside of the pipe.

Where a pipe consists of several layers (for example PEX with a certain anti-permeation layer like EvOH (Poly ethylene vinyl alcohol), it was checked visually after testing to ensure the bonding of the layers was still intact. All PEX pipes, with and without EvOH layer that Gastec has tested so far have passed this test.

Multilayer pipes containing an aluminium layer have not been tested, since the aluminium barrier layer will provide enough protection against all possible gas components.

The third question takes more to answer satisfactorily. Odorant is an additive to natural gas which acts as an alarm trigger for people: if one smells the odorant, it would normally mean that there is a gas leak somewhere. Just like methane, odorant also permeates through plastic gas pipe. In gas distribution systems outdoors this has never been considered a major problem, because the amounts of odorant that would eventually permeate through the pipe wall, are being diluted immediately as soon as they reach the ground surface.

However, although the odorant itself is not dangerous or poisonous in the typical concentration used, one can understand it is absolutely necessary that the odorant can not be smelled within a building. Even if the pipe would not allow appreciable methane permeation through the pipe wall, it could still let through odorant. Therefore, plastic pipes to be used inside building to transport natural gas have to be odorant-tight as well.

Gastec has carried out an extensive research programme to determine the permeability of odorant through the pipe walls of different plastic pipe systems. The odorant in this case was THT, which stands for tetra hydro thiophene, an odorant commonly used for natural gas.

The different pipe systems that have been investigated are:

- PEXa with EvOH layer (ethylene vinyl alcohol); this polymer is normally used to prevent the permeation of oxygen through the pipe wall in case of PEX indoor central heating systems,
- PEXa without EvOH layer,
- PEXb without EvOH layer,
- PEXc without EvOH layer,
- PEX/Al/PEX,
- PE/Al/PE,
- PE100 (HDPE) and
- PE80 (MDPE).

The purpose of the research programme was to determine the requirements for the allowable degree of permeation of the odorant in different situations and which pipe systems, including the connections, can meet these requirements during 40 years, the minimum economical lifetime of a flexible indoor gas pipe system. It was also studied which amount of odorant could accumulate in casing pipes around the flexible gas pipe, which in certain situations are obligatory to install according to the installation regulations.

During the research programme both qualitative as quantitative testing methods have been used. The qualitative testing method existed of a “smell test” carried out on different flexible pipes (see list above), through which natural gas was led continuously. The concentration of odorant in the gas was five times higher than usually used in practice. In all cases no odorant could be smelled after 7.5 till 10.5 months of exposing of the pipe systems to natural gas with a high concentration odorant, neither when after this period the concentration of the odorant was raised to 20 times the normal value. However, in all cases the tests were carried out on pipes without a casing pipe.

The quantitative test was based on accurate measurements of weight losses of closed pipe segments that were filled with a saturated odorant (THT) vapour in air . Even with this extremely high concentration[8-10] of THT (72,400 mg/m^3, while this normally is 18 mg/m^3), all multilayer pipes containing an aluminium layer showed no weight loss and therefore absolutely no permeation of odorant through the pipe wall during the whole testing period (> 150 days).

On the contrary, all other tested plastic pipe systems without an aluminium layer showed a certain degree of permeation, although only after a considerable 'incubation time', except for the PEXa pipe with EvOH layer (**Figure 1**).

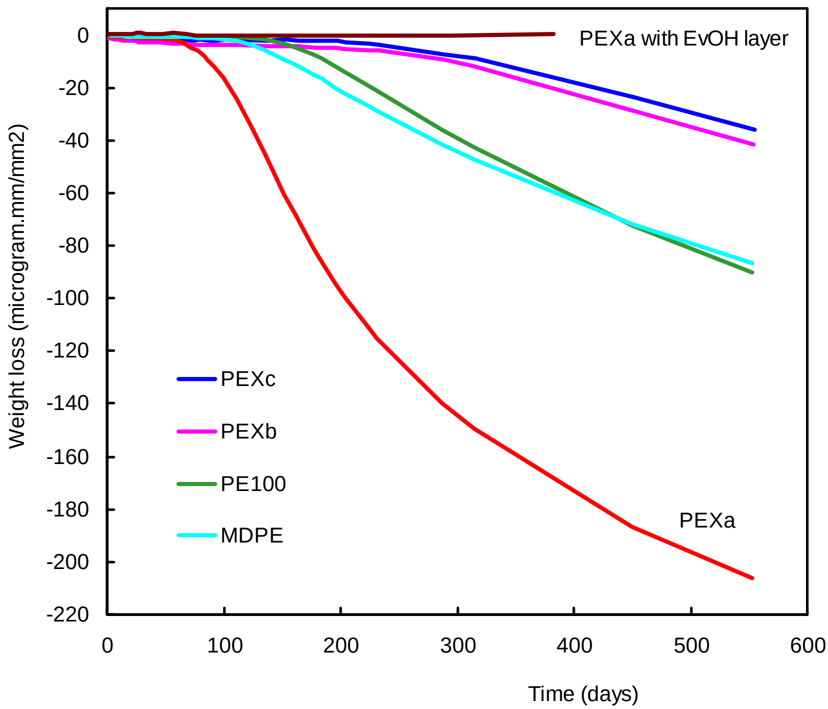

Fig. 1 Normalised weight losses by permeation of odorant (THT) through the pipe walls of different PE and PEX pipes. Measurements carried out with saturated odorant vapour in air (72,400 mg/m^3).

Under these extreme testing conditions, the PEXa pipe with EvOH layer showed no permeation at all, even not after continuing testing for over a year. From this test it can be concluded that, besides an excellent barrier against oxygen permeation, the EvOH layer also provides a very effective barrier against odorant permeation. Although not tested in this research programme, it should be noted that EvOH is also commercially available as a protection layer for PEXb and PEXc pipes and will most likely function equally effective.

The test results show that the permeation phenomena are much more complicated than described by the commonly known mathematical formulas for permeation. With PE and PEX pipes without an aluminium layer and an EvOH layer, after one to a few months a spontaneous accelerated permeation will start. Such a delayed breakthrough is in agreement with findings on odorant permeation though MDPE water pipes in the U.K.[11]

This delayed breakthrough not only occurs at very high THT contents in air, as shown in **Figure 1**, but also at a THT content of 347 mg/m3 in natural gas (**Figure 2**), which is much closer to practical value of 18 mg/m^3.

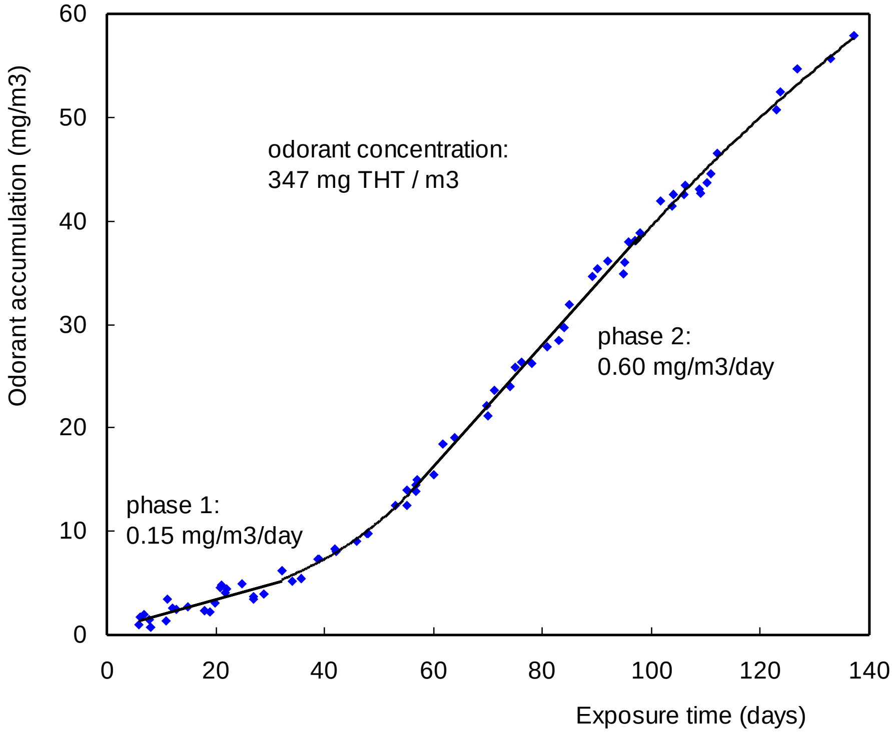

Fig. 2 Permeation through a 18 mm diameter PEXa pipe without EvOH layer, filled with natural gas containing 347 mg/m^3 THT odorant and accumulation within a casing pipe.

These phenomena can be explained in the following way.

In the first permeation phase, in **Figure 1** up to about 1 month of exposure, the PEX pipe has not yet become saturated with THT and the permeation rate is still relatively low.

The second permeation phase is the consequence of a long-term exposure to odorant-rich natural gas and the structural changes in the plastic material that are caused by this. In fact when phase 2 sets in after about 1 month, very slight swelling occurs, which is almost immeasurably low and completely unimportant in practice, caused by the presence of dissolved THT in the pipe wall. As a consequence of this swelling, more space inside the material becomes available to take up more THT and the permeation rate increases as well.[7, 12, 13] When the polymer network has swollen to its maximum capability at the given THT concentration, a second permeation phase sets in. This second phase also shows linear permeation in time, but the permeation rate has increased with a factor 4 with respect to the first phase.

Furthermore, the permeation rate through the wall of a PEX pipe is dependent on both the concentration of THT in the natural gas and the accumulated amount of THT outside the pipe, e.g. in a corrugated plastic casing pipe. Finally the history of the pipe may have an influence on the obtained results.

Because of these phenomena the permeation speed will only slowly react to changes in the THT concentration, both inside and outside the pipe. This also means that for permeation measurements at least an exposure time of three months shall be chosen to ensure the collection of reliable results.

Although obtaining the permeation coefficient for THT through PEX pipes was attempted, all these complex factors have avoided this. The permeation coefficient is too dependent on the circumstances during testing and in practice and on the period these circumstances existed.

However, it can certainly be concluded that in case of PEXa pipes without an EvOH layer and installed with a casing pipe, sooner or later in the second phase of the permeation process (i.e. after a few months) the odorant accumulation in the space between pipe and casing becomes inadmissibly high. Consequently a detectable smell of THT vapour builds up in this space. This phenomenon can even occur when the air between the PEXa pipe and the casing pipe is regularly refreshed, for example by natural draft or ventilation. Only when this air is being refreshed about 50 times per hour, no odour problems occur. However, in practice this situation will hardly occur.

Although all other tested PE and PEX pipes (without EvOH layer) show a little less permeation than the PEXa pipe, also in these cases the non-desirable second phase with accelerated permeation will be reached eventually. Therefore PEXb and PEXc without EvOH layer also inappropriate to be used as indoor gas pipes installed in casing pipes.

As far as the permeation resistance concerns, PEXa, PEXb and PEXc pipes are suitable to be used for indoor gas installation, as long as they are provided with a EvOH layer, whether this layer is built in the pipe wall or covers the outside of it. If the EvOH layer is on the outside of the pipes, it is expected that small defects in this layer, e.g. accidentally caused during installation, will not lead to situations where the odorant can ever be smelled. This is because the size of the damaged surface will always be negligible with respect to the total intact surface of the pipe.

It has been mentioned before that PEX pipes with an aluminium layer show no permeation of odorant at all. This is also valid for PE pipes with an aluminium layer. As far as the resistance to odorant permeation concerns, these two pipe systems (PEX/Al/PEX and PE/Al/PE) are therefore suitable for use for indoor gas installations as well.

Conclusions of the Research Programme on Odorant Permeation

Summarised, the following conclusions can be drawn from the results of the extensive research programme on the permeation of odorant:

1. In the case of multilayer pipes consisting of PEX-aluminium-PEX and PE-aluminium-PE the permeation of odorant through the pipe wall is zero. Pipe systems made of

these pipes are therefore suited for use in indoor gas installations, as far as the resistance to odorant permeation concerns.

2. In the case of PEX pipes containing an EvOH layer, present in or as a coating on the outside or inside of the pipe, the permeation of odorant through the pipe wall is negligible. Pipe systems made of these pipes are therefore suited for use in indoor gas installations, as far as the resistance to odorant permeation concerns.
3. The permeation of odorant through pipes made of PEXa, PEXb or PEXc, without EvOH layer, show an inadmissible degree of permeation of odorant, when installed in a casing pipe (e.g. corrugated PE pipe). Since the regulations for installation of PEX pipes for indoor gas installations prescribe the use of such casing pipes in certain situations, it is strongly recommended that PEX pipes without EvOH layer are not used for indoor gas installations.

MECHANICAL ASPECTS

The mechanical aspects of flexible plastic indoor gas pipe systems can be roughly divided in two groups: aspects concerning the pipe itself and aspects concerning the mechanical connection between the pipe and the metal fitting.

As far as the pipes are concerned, the most important desirable properties are the lifetime (economical lifetime is 50 years) of the pipe and the resistance to buckling. The first property can be covered by the standardised tests to determine the long-term hydrostatic strength by carrying out regression analyses (ISO/DIS 9080). For most PEX and multilayer pipes on the market this already has been done successfully for use in water and heating systems. Since the maximum pressures in these applications are considerably higher than for indoor gas systems, no problems have been seen so far and are none are expected.

Furthermore, it is important that the pipe shows a certain resistance to buckling. This is needed because sharp bends are often needed during installation. The resistance can be determined by carrying out defined bending tests. In the GASTEC QA Approval Requirements[1, 2] the requirement is that no buckling shall occur at a bending radius of 5 times the outside diameter of the pipe.

The joints between the pipe and the fitting shall also show sufficient resistance against bending and pull out forces. These aspects are covered by different requirements in the relevant GASTEC QA Approval Requirements and are similar to requirements already known for mechanical joints in other gas distribution systems making use of plastic pipes.[1, 2]

SAFETY ASPECTS

The first thing becomes obvious when plastics are considered for use in indoor gas piping systems is the fire safety. It cannot be denied that the fire resistance of a plastic pipe is low, in fact during a fire a plastic like PEX or PE will simply burn away after a while. Therefore the fire safety aspect must be solved in another way. It is important that during a fire the amount of escaping gas is restricted. This is possible for example by building safety devices into the system. One of the methods is to apply excess flow valves at the beginning of each pipe, whilst every gas appliance is fed from a manifold by a separate pipe with no intermediate connections. These devices shut off the gas supply when the flow exceeds a certain level, for instance when the pipe is damaged by fire. Next to these devices temperature sensitive fittings can be built into the system at carefully selected positions, which will shut the gas supply when a certain temperature is reached. Both excess flow valves and temperature sensitive shut off valves are already commercially available, tested and have been applied successfully in flexible indoor gas piping systems.[4, 5]

Another possibility to protect the pipe system against fire is to install the pipes and the mechanical joints in protected areas like stone walls, concrete floors etc. Obviously there is a chance that the pipe will still start leaking during a severe fire, but in this case the building is already completely lost anyway. This approach to safety by installing the flexible pipe system inside walls and floors is followed in the official Dutch guidelines for installation of PEX, multilayer and corrugated steel piping systems for indoor gas installations.[6]

Finally, because of the reduced number of fittings in total compared to copper and steel piping systems, the general chance of leakage is lower and the explosion safety is improved.

ECONOMICAL ASPECTS

The use of plastics in flexible indoor gas piping systems can reduce the total installation costs compared to traditional metal piping systems. The total reduction of cost is strongly dependent on the layout of the pipework system as prescribed in the national installation regulations. The average reduction that can be achieved in a normal gas installation is about 30%. In some favourable cases, such as the Dutch system, it can be even more than 50%. However, in the case of very short pipe lengths the advantage will be low or even negative compared to the traditional metal systems. This is because the largest contribution to the reduction in costs is the considerable shorter overall installation time, due to the enhanced flexibility, handling and the ease and speed of the connections.

Furthermore, if national installation regulations prescribe obligatory extra safety devices compared to metal piping systems, the overall cost reduction may be lower than the average 30%.

Finally, an important contribution to cost efficiency can be that the installer is already used with similar systems for potable water, central heating and floor heating. In this case considerable cost savings can be reached in connection tools and training of the installers. However, if rubber rings are being used as sealants in the metal connection fittings, a slight disadvantage at the moment is that the rubber quality that is normally used for water is not suitable for gas as well. This disadvantage will be taken away as soon as the present attempts to develop a rubber quality that is suitable for use in both water and gas applications are successful. This problem can be solved in other ways as well, for example by fittings which do not need rubber rings to seal properly.

THE FUTURE

What opportunities exist for flexible plastic indoor gas pipe systems in the near future? A lot will depend on the ease of acceptance of these systems in different countries over the world. In The Netherlands the systems using all available kinds of PEX with EvOH barrier, PEX/Al/PEX and PE/Al/PE pipes, mechanically connected with all kinds of brass or steel fittings are already fully accepted. There are already numerous (GASTEC QA) approved systems and the installation regulations also foresee the possibility to apply these systems. Next to this, training programmes have been set up to train and certify installers to allow them to install such systems.

As already mentioned in the introduction, in Switzerland there is already experience with flexible pipe systems, in this case multilayer pipe systems using PEX/Al/PEX pipes.

In Germany the multilayer pipe systems containing aluminium have already been accepted as well. Also here the requirements for the system and the regulations for installation are now available. However, up to now fully plastics pipes such as PEX are not yet allowed, mainly because of their lower fire resistance.

Furthermore, an international ISO standard is being developed at the moment in which the requirements for multilayer piping systems are being described. In this standard, multilayer piping systems will be described that either consist out of two or more plastic layers (P-pipes) or consist of more layers of which at least one layer is made of aluminium (M-pipes).

A final, very new development is to introduce plastic fittings to make the mechanical connection, instead of metal fittings. In other applications, such as sanitary and heating, multilayer pipes, as well as PEX pipes, can already be mechanically connected with plastic fittings. In these cases the fitting is made from the high-tech plastic PPSU (Polyphenylsulphone).

At this moment Gastec is performing an evaluation programme for a manufacturer of such a resin to determine the suitability of this material to be used in fittings for indoor gas pipe systems. The first results look promising and the final results are expected to be available at the end of this year.

If the results turn out to be satisfactory, it is possible to deliver a pipe system for indoor gas distribution which consists (almost) completely out of plastic. Who would have thought of that five years ago?!

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