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Production techniques for polyurethane pre-insulated pipes and foam systems suitable for the manufacture of high quality pipes applied in district heating

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Abstract

Polyurethane insulated pipes have been widely accepted and used in district heating systems. The most commonly used manufacturing technique is still the discontinuous, pour-in-place technique where the reacting foam system has to fill the annular space between a pre-assembled service and casing pipe. Special foam systems are required, in particular excellent flow properties are necessary to ensure an even property distribution along the pipe. Another key requirement is the ability of the high long-term thermal resistance of the foam to cope with service temperatures of district heating networks up to 140°C.

More advanced pipe production techniques have also been developed that offer some cost saving potential for the production of pre-insulated pipes, through a reduction of the foam filling density and a reduction of the casing pipe thickness. These so-called continuous manufacturing techniques however, require modified foam systems that differ in reactivity, viscosity build-up and cure characteristics.

This article provides an overview about the advantages and disadvantages of various pipe manufacturing techniques and provides guidelines for the selection of the most suitable technique depending on the individual situation of a pipe producer. Further, polyurethane foam systems suitable for different pipe manufacturing techniques, all complying with the European norm EN 253 for pre-insulated bonded pipe systems for underground hot water networks, are discussed.

Introduction

Polyurethane pre-insulated pipes have been widely accepted for use e.g. in district heating systems. The applied PU-foam systems must fulfil various requirements regarding foam processing and product performance. A number of different pipe manufacturing techniques can be used for the production of polyurethane pre-insulated pipes.

Requirements for rigid polyurethane foam for the production of pre-insulated pipes

For discontinuous pipe filling, which is the technique most widely used for the production of pre-insulated pipes, the reacting foam systems must be able to completely fill the annular space between service pipe and casing pipe over lengths up to 16m. Therefore, a foam system requires excellent flow properties to obtain an even density distribution along the pipe. A good adhesion of the foam to the pipes is necessary to ensure the long-term performance of the pipe composite. For the insulation efficiency a low foam thermal conductivity is inevitable. A high long-term heat resistance is necessary as district heating networks operate with service temperatures up to 140°C. High mechanical properties, e.g. compressive strength, are required to enable the foam to withstand high loads, e.g. when the pipe composite is transported or buried in the ground. The minimum properties polyurethane foam must fulfil are outlined in the European quality norm for pre-insulated bonded pipe systems for buried hot water networks, EN 253 [1]. Similar quality norms are being set up in China at present.

For the manufacture of pre-insulated pipes essentially three alternative types of rigid polyurethane foam systems are being used at present:

- **fully water blown systems**
- **dual blown systems using water and the physical blowing agent HCFC-141b**
- **dual blown systems using water and the physical blowing agent cyclopentane**

Due to the phase out of HCFC-141b, foam systems using HFC blowing agents instead of HCFC-141b are being developed at present.

Pipe filling techniques and processing recommendations

A number of different techniques can be used for the production of pre-insulated pipes. Obviously, each technique has its advantages and disadvantages. We can distinguish between two main classes of production techniques, the discontinuous and the continuous production techniques. The suitability of a production technique depends on the particular situation of each individual pipe producer. In the following pages, the most widely used production techniques will be discussed.

Discontinuous techniques

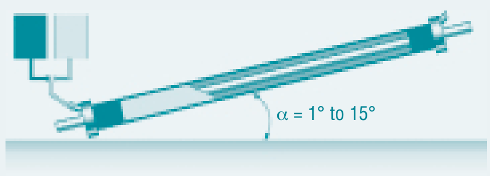
In discontinuous production techniques a pipe pre-assembly is made by positioning the steel inner pipe centrally in a slightly shorter high density polyethylene (HDPE) casing pipe. To keep the steel pipe in the centre of the casing pipe, distance holders are arranged around the steel pipe. At both ends the gap between the steel and the casing pipe is sealed off by end-caps that fit tightly around the steel and the HDPE pipes. The end-caps are equipped with holes for foam injection and air venting. In principle, pipes of any length up to approximately 16m can be used, but standard steel pipe lengths are 6, 12 and 16m.

Key parameters for good quality pipe filling include temperature control of components and pipes, proper treatment of the pipe surfaces and filling density and time. Polyol and isocyanate temperature should preferably be 20-23°C. The pipe assembly should, especially in winter time, be pre-heated to between 20 and 30°C. Lower temperatures of the pipe assembly will result in heat losses from the foaming mixture and insufficient reactivity at the foam/pipe interface. This can result in higher foam friability and reduced adhesion of the foam to the pipes and one may also require more foam to fill the pipes completely.

For proper adhesion, the steel pipes should be free of grease, oil and rust. It is recommended to pre-treat the HDPE casing pipe by either flame or Corona treatment to ensure a strong bond between the foam and the casing pipe. The output of the dispensing machine should be adjusted such that the calculated amount of the mixed components can be injected well within the system cream time. The recommended fill density depends on the actual pipe dimension. However, the filling density should always be sufficiently high to enable the foam to completely fill the pipe well within the system fibre time. If the foam does not reach the pipe ends before the system fibre time, the foam will be stretched, i.e. foam cells become elongated. This will result in poor mechanical strength of the foam at the pipe ends.

Pour-and-rise technique

Figure 1



Pour-and-rise technique

In the pour-and-rise technique, the pre-assembled pipes are normally held to an angle up to 15° to the horizontal, see Figure 1. The applied angle depends on the particular pipe dimensions and the flow-ability of the system used.
The required amount of foaming mixture is injected into the cavity between the steel and the HDPE pipe via the hole in the end-cap at the bottom of the pipe assembly. Here the foam starts to expand. The hole is sealed with a stopper as soon as the foam reaches it. The foam is then forced to expand in an upward direction along the length of the pipe. The displaced air escapes via the air venting hole in the end-cap at the top of the pipe. As soon as the expanding foam reaches the top venting hole, this hole is sealed off as well. The assembly is left to cure for some time before removing the end caps.

The main advantage of this technique is the ease of production. The applied pipe angle is not very critical. The skill level of the operators can therefore be low. The technique is very flexible in the sense that a large range of pipe dimensions can be produced with minimal changes to the set-up.
The main disadvantage is the uneven distribution of foam and hence mechanical properties along the pipe. The highest foam density will be found in the bottom of the pipe while the top end will have the lowest foam density. Because of the relatively long path the foam has to travel in the narrow pipe cavity, a high overpack is required. The availability of a pipe filling table with adjustable angle is preferred.

the suitability of a production technique depends on the particular situation of each individual pipe producer

Top filling technique

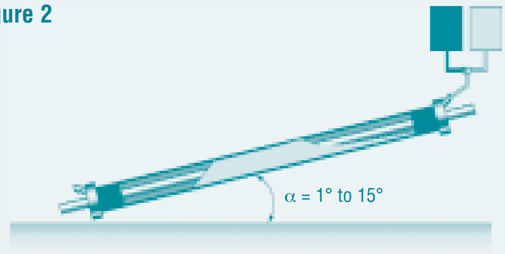


Figure 2

Mid-point filling technique

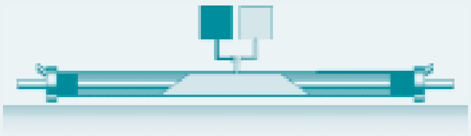


Figure 3

Top filling technique

In the top filling technique, the pre-assembled pipes are also normally held to an angle of 1 to 15° to the horizontal, see Figure 2. In this case, however, the required amount of foaming mixture is injected into the cavity between the steel and the HDPE pipe via the hole in the end-cap at the top of the pipe assembly. The force of gravity makes the relatively low viscous mixture flow down the pipe. The extent of this flow depends on the angle of the pipe assembly, the higher the angle, the more material flows down. This already gives an initial distribution of the foam along the pipe before the real expansion phase sets in. The foam then fills up the cavity from the centre of the pipe to both ends. Experience has shown that the best property distribution is obtained when the foam reaches the venting hole at the bottom end of the pipe some 20 seconds before it reaches the top end. Obviously the venting holes are sealed as soon as the foam escapes from them.

The initial material distribution in the pre-expansion phase reduces the path the foam has to travel to fill the cavity completely. This allows for lower foam overpack or lower filling density to be used. Longer pipes can be filled more easily. A good foam distribution giving a narrow density distribution along the pipe can be achieved if the correct pipe angle is used. However, the pipe angle is more critical than in the pour-and-rise technique, hence the skill level of the operators has to be somewhat higher. The availability of a pipe filling table with adjustable angle is highly recommended.

Mid-point filling technique

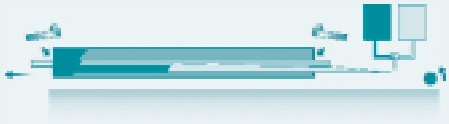
In the mid-point filling technique the pipe assembly is kept horizontal, see Figure 3. The required amount of foaming material is injected via a hole in the middle of the HDPE casing pipe. With this technique, the path the foam has to travel to fill the pipe is reduced to half the length of the pipe. This allows the use of a lower overpack and makes it easier to fill longer pipes with acceptable density distributions. Air venting takes place via holes in both end-caps. The risk of air entrapment is somewhat higher than with the other techniques. The injection hole in the casing pipe is plugged provisionally directly after the foam injection. After the curing of the foam, the hole has to be welded to seal it completely. However, it potentially remains a weak spot in the pipe.

Lance withdrawal technique

Figure 4

Pull-through technique

Figure 5



Lance withdrawal technique

The lance withdrawal technique is a discontinuous production technique with the foam distribution of a continuous process. In this technique, the pipe pre-assembly is kept in a horizontal position. The filling machine is modified in such a way that a miniature mixing head is positioned at the end of a lance, see Figure 4. The lance is inserted in the pipe cavity such that the mixing head is positioned at the far end of the pipe. Obviously, the mixing head has to be designed to fit in the relatively small area between the inner service and the outer casing pipe. This is best achieved in combination with a high pressure foaming machine. The dimensions of the mixing head may limit the use of this technique for very small diameter pipes. When the mixing head is positioned correctly, the foam dispense is started. During the dispense, the lance is withdrawn gradually. This ensures a good distribution of foam along the pipe, independent of the length of the pipe. The foam flow path is reduced significantly as it only has to flow around the pipe. This allows for a very low overpack to be used. The laydown of the foam along the pipe with the moving mixing head removes the restriction on the dispense time associated with top filling or pour-rise technique. This opens the opportunity to fill very large pipes with relatively small capacity foaming machines.

Pull-through technique

The pull-through technique is similar to the lance withdrawal technique, in the sense that it is a discontinuous production technique combined with a continuous foam application. The pipe pre-assembly is kept in a horizontal position. The foam mixture is applied onto a thin, semi-permeable paper web, located under the inner service pipe, which is pulled through the pipe cavity, see Figure 5. The foam starts to expand inside the pipe whilst being pulled through to the other end. It has to flow only a short distance, which allows work with low foam overpack rates. Uniform foam properties along the pipe can be obtained. The even distribution of the reacting foam mixture allows long and narrow pipes to be filled, e.g. lengths up to 30m can easily be produced. A disadvantage of this technique is the paper web that stays in the foam, which can lead to adhesion problems between foam and casing pipe. Foam output rate and paper web feed need to be well coordinated.

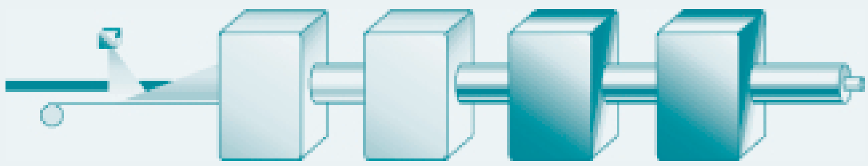
Continuous techniques

Continuous pipe production techniques consist of two stages. In the first stage, the foam is applied on the inner pipe in a moulding or spray operation. In the second stage, the casing pipe is extruded or wound around the pre-shaped foam. Continuous manufacturing techniques require a change of foam reactivity, viscosity build-up and cure characteristics which necessitate the use of modified foam systems [2].

Continuous techniques allow a fast and consistent production of a large number of pipes of the same dimensions, at comparatively low variable costs. A reduction of the foam overpack, the filling density and a reduction of the casing pipe thickness can lower raw material costs for the pipe manufacturer. However, changes in pipe diameter and insulation thickness can involve long set-up times which makes a continuous technique less flexible than a discontinuous technique. In combination with the high capital investment required for a continuous production technique, these techniques are mostly suited for large pipe manufacturers who produce large quantities of pipes with the same diameter.

Continuous moulding technique

Figure 6

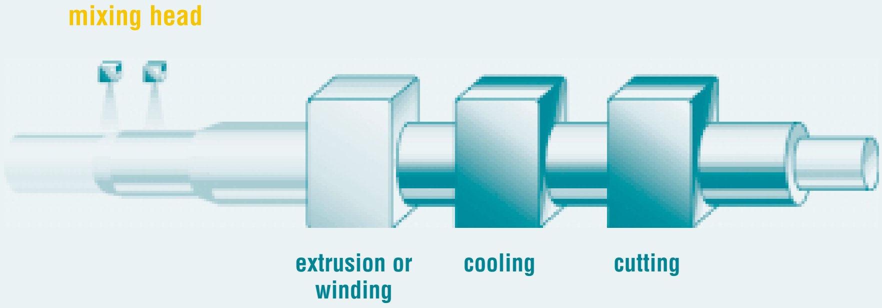


Continuous moulding technique

In the continuous moulding technique, see Figure 6, the reacting mixture is continuously laid down on a polyethylene (PE) film, above which the inner pipe is positioned. The PE film is pulled into a circular, temperature controlled, moulding section together with the inner pipe. Here the foam is shaped around the pipe and reaches its full expansion. A very low foam overpack is applied. At the end of the moulding section the foam should have cured sufficiently to gain the required mechanical strength and avoid further post-expansion.
The HDPE pipe can then be extruded around the foam and the finished pipe is cut to the required length. In comparison to discontinuous pipe manufacturing techniques, this processing technique does not require much flow in the length direction of the pipe. However, the reacting foam has to flow around the medium pipe to fill the entire pipe section. This method is suitable for small and medium pipe diameters. In particular for the production of flexible pipes [3], which are normally made in lengths of several hundred metres and subsequently coiled up, the continuous manufacturing technique is perfectly suited as this technique imposes no restrictions to the length of the pipe produced.

Spray onto a rotating pipe

Figure 7



Continuous spray technique

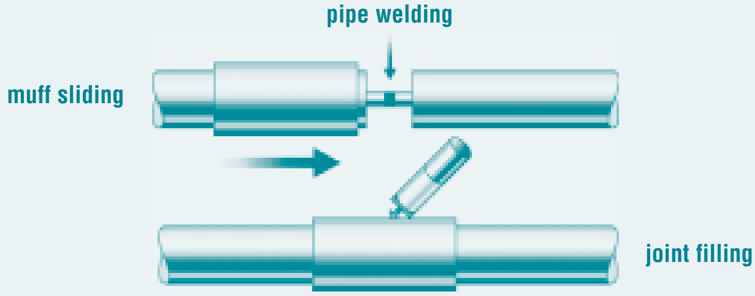
In the continuous spray technique the reacting foam mixture is sprayed on the outside of the rotating medium pipe, see Figure 7. Obviously the foam has to react very quickly, so that the foam adheres well to the pipe surface and does not spin off. Various layers of foam may be applied to obtain the required insulation thickness. A very uniform foam is created over an extremely short flow path. Virtually any insulation thickness can be produced by spray application. Large and long pipes can be insulated using smaller foaming machines.

Afterwards, the HDPE casing pipe is extruded or wound around the insulation. Applied foam densities can be lower, the HDPE casing pipe can be thinner and hence material savings are possible. In practice, the spray technique is particularly suited for large diameter pipes. Application of this technique to small diameter pipes may generate too much waste and hence may not be economical. As for the continuous moulding technique, longer set-up times are required when changing pipe dimensions.

Associated filling techniques

Joint filling technique

Figure 8



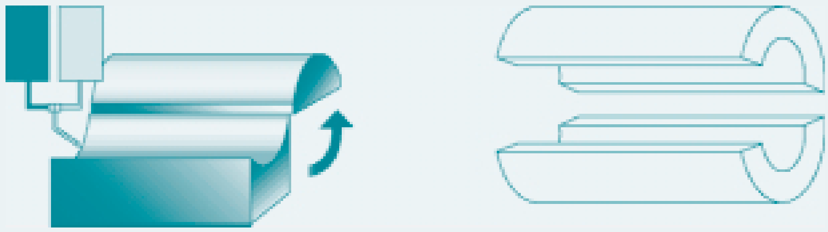
Joint filling

When a district heating network is constructed, the 6 to 16m long pipes are joined together after they are laid down. This involves the welding of the steel pipes, the welding of the HDPE sleeve and the filling of the resulting cavity with PU foam, see Figure 8. The joints can be considered to be the weakest points in the network. It is therefore of utmost importance to have qualified and experienced staff to carry out the work and to ensure optimal on-site working conditions. Obviously the key parameters for good quality pipe filling mentioned before, like temperature of components and pipes, condition of the pipe surfaces and filling density, also apply to on-site joint filling.

The components for joints are often mixed by hand, although small on-site foaming machines are also used. Especially for hand-mixed foam the reactivity of the joint system has to be lower than for normal pipe systems. This gives sufficient time for proper mixing and careful pouring of the mixed components into the cavity via the filling/venting hole in the top of the sleeve.

Production of pipe scales

Figure 9



Pipe scales

Sometimes pipe scales are used to fill a joint cavity or repair the insulation on an existing pipe network. Pipe scales are produced in half-pipe shaped moulds, see Figure 9, or cut from foam blocks. To avoid the foam sticking to the mould, release agent is applied to the mould. For proper processing and skin formation, the mould is preferably heated to 30-40°C.

In principle, the foam requirements of pipe scales are the same as for foam used in pre-insulated pipes, although there is obviously no adhesion between the pipes and the foam. The systems used for the production of pipe scales may therefore be the same as the systems used to fill entire pipes. However, to increase the production speed the reactivity of the system can be increased via the addition of a catalyst. This will allow for a shorter de-mould time, i.e. the time before the foam can be taken out of the mould without distortion of the shape. A lower overpack level, hence a higher free rise density of the system, will also reduce the de-mould time.

Polyurethane foam systems for various pipe filling techniques

In our laboratory we have developed a variety of foam systems for different market requirements and pipe manufacturing techniques. These systems have been successfully implemented on an industrial scale.

Fully water blown systems

In water blown systems the expansion of the polyurethane foam is due to the formation of carbon dioxide which is generated from a reaction of water with isocyanate.

Fully water blown systems exhibit a somewhat higher thermal conductivity due to the lower insulation capacity of carbon dioxide compared to other blowing agents, e.g. HCFC-141b or cyclopentane. Beside carbon dioxide, the reaction of water with isocyanate also generates a high level of polyurea in the foam. These polyurea units provide an increased thermal stability. However, the higher level of polyurea will also increase the foam friability, in particular for low reactivity systems. This can lead to reduced adhesion between the foam and the casing pipe.

Water blown foams, if correctly formulated, show a very fine cell structure and provide excellent mechanical and thermal properties. Certificates, issued by accredited institutes prove a continuous calculated operating temperature (CCOT) higher than 140°C for a period of 30 years. Water blown foam systems are environmentally friendly and can be processed on standard equipment. However, a careful temperature control of pipes and ingredients is required to avoid foam friability. Huntsman Polyurethanes have developed a series of fully formulated water blown systems comprising polyol, surfactant, catalyst and water. Table 1 displays typical properties of the foam system Daltofoam TE44204/Suprasec 5005. This system provides good flow properties and has a broad processing window. Due to the extended cream time, the foam injection time can be prolonged. Hence, pipe filling with small capacity foam dispensing machines is facilitated. Large diameter pipes are easier to fill.

Dedicated foam systems for the production of fittings are available as well. Systems for joint filling have been developed that can be applied down to ca.0°C. Systems for the lance withdrawal technique, the pull-through technique and the continuous pipe moulding technique have been developed and commercially implemented.

Table 1: Properties of fully water blown system recommended for discontinuous pipe filling

Property	Unit	Test method	Typical value	EN 253 requirement
Polyurethane rigid foam				
Average cell size	mm	EN 253, 5.3.2.1.	0.2	<0.5
Closed cell content	%	EN 253, 5.3.2.2.	94	>88
Foam density	kg/m³	EN 253, 5.3.3.	86	>60
Compressive strength	MPa	EN 253, 5.3.4.	0.55	>0.3
Water absorption	%vol	EN 253, 5.3.5.	6.1	<10
Pipe assembly				
Shear strength before ageing				
axial at 23°C	MPa	EN 253, 5.4.2.1.	0.46	>0.12
axial at 140°C	MPa	EN 253, 5.4.2.2	0.24	>0.08
tangential at 23°C	MPa	EN 253, 5.4.3.	0.73	>0.20
Thermal conductivity at 50°C	W/m.K	EN 253, 5.4.5.	0.030	<0.033
Calculated continuous operating temperature	°C/30 years	EN 253, 5.4.4.	142	>120

Table 2: Properties of HCFC-14lb blown system recommended for discontinuous pipe filling

Property	Unit	Test method	Typical value	EN 253 requirement
Polyurethane rigid foam				
Average cell size	mm	EN 253, 5.3.2.1.	0.2	<0.5
Closed cell content	%	EN 253, 5.3.2.2.	94	>88
Foam density	kg/m³	EN 253, 5.3.3.	84	>60
Compressive strength	MPa	EN 253, 5.3.4.	0.59	>0.3
Water absorption	%vol	EN 253, 5.3.5.	6.0	<10
Pipe assembly				
Shear strength before ageing				
axial at 23°C	MPa	EN 253, 5.4.2.1.	0.59	>0.12
axial at 140°C	MPa	EN 253, 5.4.2.2	0.36	>0.08
tangential at 23°C	MPa	EN 253, 5.4.3.	1.14	>0.20
Thermal conductivity at 50°C	W/m.K	EN 253, 5.4.5.	0.028	<0.033
Calculated continuous operating temperature	°C/30 years	EN 253, 5.4.4.	140	>120

HCFC-141b/water dual blown systems

The HCFC-141b/water dual blown route is based on expansion of the polyurethane foam partly by carbon dioxide, generated from the reaction of water with isocyanate, and the physical blowing agent HCFC-141b.

The addition of HCFC-141b reduces the viscosity of the polyol significantly. Due to the excellent flow properties, HCFC-141b/water dual blown systems are easy to process. Compared to fully water blown systems, the thermal resistance is in general somewhat lower, the mechanical properties are comparable and the initial thermal conductivity is lower. HCFC-141b blown systems can be processed on standard equipment.

The use of HCFC-141b as a blowing agent is restricted in some countries and HCFC-141b will be phased out in the future since it has an ozone depletion potential (ODP) and a global warming potential (GWP). Therefore the local legislation has to be checked carefully. Potential alternatives to HCFC-141b can be, for example, HFC-134a, HFC-245 or HFC-365 which have an ozone depletion potential of zero and a low global warming potential. Due to the planned phase-out of HCFC-141, we are presently developing foam systems where HCFC-141b is being replaced by HFC-134a, HFC-245 or HCF-365, or combinations thereof.

HCFC-141b blown foams, if correctly formulated, provide excellent mechanical and thermal properties. Lifetime certificates prove a CCOT of 140°C for a period of 30 years. Huntsman Polyurethanes have developed a series of fully formulated systems comprising polyol, surfactant, catalyst, water and HCFC-141b. Table 2 displays the typical properties of the systems Daltofoam TE24201/Suprasec 5005.

Dedicated foam systems for the production of fitting and joints are available as well.

Cyclopentane/water dual blown systems

The expansion of the polyurethane in these systems is partly based on carbon dioxide and partly on the physical blowing agent cyclopentane. The thermal stability of these foams is comparable to fully water blown systems. The ozone depletion potential of cyclopentane is zero and the global warming potential of <0.01 is very low. Therefore these foams can be considered as environmentally friendly.

However, for the handling of cyclopentane strict precautions have to be taken. Cyclopentane is a flammable liquid with a flash point far below room temperature. Mixtures of air and pentane are flammable and can be explosive. Therefore an ignition source must be avoided. In view of these safety precautions, equipment changes are required before pentane containing systems can be processed.

Huntsman Polyurethanes have developed a series of cyclopentane/water blown formulations for the production of pre-insulated pipes. Cyclopentane is always to be added to the polyol in-situ prior to pipe filling. Our cyclopentane blown systems show excellent mechanical and thermal properties.

Lifetime certificates prove a CCOT higher than 140°C for a service period of 30 years. Table 3 displays the typical properties of the system Daltofoam TE34201/Suprasec 5005. This system provides improved flow properties and has a broad processing window. The improved flow-ability can allow a reduction of the pipe filling density, in particular when used with the top-filling technique, i.e. cost savings can be achieved by pipe manufactures through reduced foam consumption. Further, pentane blown systems provide the lowest initial thermal conductivity compared to water and HFCF-141b blown systems. The thermal conductivity ageing rate, i.e. the deterioration of the insulation capacity of the foam as a function of time, is lower with pentane blown foams as compared to fully water blown foam systems [4].

Modified systems are available, also certified according to EN 253, but having a CCOT of 149°C for a service period of 30 years. For the continuous moulding technique, a foam system was developed, which has a CCOT of 146°C for a service period of 30 years. Dedicated foam systems for the production of fitting are available as well.

Table 3: Properties of cyclopentane blown system recommended for discontinuous pipe filling

Property	Unit	Test method	Typical value	EN 253 requirement
Polyurethane rigid foam				
Average cell size	mm	EN 253, 5.3.2.1.	0.2	<0.5
Closed cell content	%	EN 253, 5.3.2.2.	93	>88
Foam density	kg/m³	EN 253, 5.3.3.	78	>60
Compressive strength	MPa	EN 253, 5.3.4.	0.45	>0.3
Water absorption	%vol	EN 253, 5.3.5.	4.3	<10
Pipe assembly				
Shear strength before ageing				
axial at 23°C	MPa	EN 253, 5.4.2.1.	0.42	>0.12
axial at 140°C	MPa	EN 253, 5.4.2.2	0.25	>0.08
tangential at 23°C	MPa	EN 253, 5.4.3.	0.64	>0.20
Thermal conductivity at 50°C	W/m.K	EN 253, 5.4.5.	0.027	<0.033
Calculated continuous operating temperature	°C/30 years	EN 253, 5.4.4.	144	>120

Conclusion

A variety of pipe filling techniques are available.
The discontinuous techniques require relatively low capital investment and are generally flexible in producing a large range of different pipe dimensions. Low to medium skilled operators are required. From the discontinuous techniques discussed, the top filling technique has our preference because it gives a good density distribution along the pipe, if the correct filling angle is applied. The continuous techniques are more suited for pipe producers who produce large numbers of equal sized pipes and can afford the high capital investment involved in the machines. Continuous production techniques can provide a cost saving potential through a reduction of the applied pipe filling density whilst still achieving the required minimum core density. Further cost savings can result from a thickness reduction of the HDPE casing pipe.

Huntsman Polyurethanes offers a range of polyurethane foam systems that are tailored to suit a particular pipe manufacturing technique. Fully water blown, HCFC-141b and cyclopentane blown systems are available and have been successfully implemented on an industrial scale. These systems are certified according the European standard EN 253. Pre-insulated pipes made with these foam systems, can be used in district heating applications but also in industrial pipe insulation application, e.g. oil pipelines.

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Biographical notes

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Jürgen Kellner received an MS degree in Chemistry from the University of Regensburg, Germany and a PhD in Organometallic Chemistry from the Technical University of Munich, Germany. He joined Shell Chemicals in 1989 and held various positions in research, marketing and market development in the field of epoxy resin. In 1996 he took up a position in the Chemical Research Centre of Shell in Louvain-la-Neuve, Belgium as a Senior Research Chemist in Rigid Polyurethane responsible for applicational research, development activities and technical service for rigid polyurethane foam insulated pipes. In 1999 he joined Huntsman Polyurethanes, Belgium, and is now responsible for the pipe insulation business.

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Rene Shen received a M.S. degree in Organic Chemistry from Shanghai Science & Technology Unversity in 1993. He joined Huntsman ICI Polyurethanes (China) Company in the technical service department in 1994. Currently he is technical development supervisor for Construction, CASE and Binders.

a variety of pipe filling techniques is available

Continuous techniques can provide a cost saving potential

Discontinuous techniques offer a high degree of flexibility