International Energy Agency

IEA District Heating

Programme of research, Development and
Demonstration on District Heating and Cooling

DISTRICT HEATING PIPING WITH PLASTIC MEDIUM PIPES STATUS OF THE DEVELOPMENT AND LAYING COSTS

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In the appendix to the report attached you will find important biliographical references. They are cited in their original language. Please look at them not as a part of the report but as a service to the reader.

Translations of special comments to figures

page 51	Aushubmaterial	excavated material
	Sandbett	sandbed
page 69	Vorlauftemperatur	outgoing temperature
	Stunden pro Jahr	hours per year
	Angen. Temp. Verteilung	accepted temperature distribution
	Grad C	centigrades
page 71	Standzeit	lifetime

93/E0299/221220/40

Dear reader,

The Executive Committee of the Implementing Agreement on District Heating and Cooling is interested to improve the impact of the R&D activities and the effectiveness of the programme.
For that reason the Operating Agent needs your support. May I ask you to be so kind to complete the following questionnaire and to sent it back to:

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INTERNATIONAL ENERGY AGENCY

Programme of Research, Development and
Demonstration on District Heating

DISTRICT HEATING PIPING WITH PLASTIC MEDIUM PIPES STATUS FOR THE DEVELOPMENT AND LAYING COSTS

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CONTENTS

1. Summary

District heating pipelines with plastic medium pipes can offer advantages in public supply systems with diameters less than DN 100. The standard design with medium pipes of cross-linked polyethylene PE-X (previously VPE) and polybutylene (PB) seem to be suitable for loads of an operating pressure of 5 bar and variable supply temperature up to 90 °C.

Pipelines with plastic medium pipes have brought cost advantages of up to 40 % compared with today's standard design of plastic compound jacket pipe with steel medium pipe. These advantages vary considerably from manufacturer to manufacturer; they differ in the northern and middle European countries considered here as a result of the level of the civil engineering costs. Savings are a result of the fast and flexible method of laying.

The low proportion of plastic pipelines in public district heating networks is primarily a result of the sensitivity to temperature and pressure and the lack of experience of the longterm behaviour. The use of these flexible systems will increase as long as the cost advantages remain and further positive operational experiences are made and temperature/ pressure levels are decreased.

2. Introduction

2.1 General

The medium pipe of a conventional district heating system is made of steel since this material is particularly suitable for withstanding thermal and pressure loads. Plastic medium pipes can be more favourable than steel for small pipelines, even though they can only stand lower temperature and pressure loads. The assembly procedure can be so advantageous that cost reductions for pipeline construction result even though the pipe material itself is often more expensive than steel pipes. To reduce the high investment costs of pipeline construction an attempt must be made to use these possible savings to the full. They are offered in the area of small pipelines and service connections for nominal diameters under DN 100.

Suitable pipeline systems with plastic medium pipes are being offered for sale in all the countries being considered here in Western, Central and Northern Europe, although not always to the same extent. For this reason, a comparison of the user practice and construction costs between the countries would be worthwhile. The work is an extension to an IEA-report, based on the status in 1985/86 [1] which concerned the construction of pipelines in areas of low heat density. A comparison of pipe systems on the market today with those considered at that time makes the rapid development experienced in this area quite clear. In fact, not one system is still being offered on the market without changes having being made. The many new developments mean that it may be assumed that there is still a considerable potential for a further development of these systems.

2.2 Present Situation

The status of the development today can be summarized in three sentences:

1. The experiences made by the manufacturers and from applications have produced a positive effect on the market, which has increased the expected turnover of established manufacturers and has also attracted new suppliers.

2. Manufacturers and users are following difficult development objectives. Plastic pipe systems will be open to professional applications and manufacturers will be able to increase their turnover only when all remaining application problems have been correctly solved.

3. The turnover of pipeline material based on cross-linked polyethylene is manytimes higher than the turnover of polybutylene systems.

These statements must be explained more in detail. The established manufacturer of plastic systems assesses the chances of these systems as positive. In addition, a competent company from Switzerland, Kabelwerk Brugg, has joined these suppliers and has introduced a new system, see section 2.3. It is also interesting to note that manufacturers of conventional systems, i.e. of plastic jacket pipes, are increasingly extending their palette of products including plastic systems, e.g. Lögstör and Dansk Rörindustri. Wirsbo has even introduced a complete system although this company already has a very high position on the market as manufacturer of basic material.

Plastic medium pipes have been applied in a large number of reference "networks" which, for several products, have already shown periods of utilization of up to 12 years. It is noticeable that the main area of sales is the small, household-oriented construction of pipelines which are served by plumbers. In the case of professional pipeline planners of the supply for communities, these systems have only been introduced in isolated projects where this type of design has been regarded as advantageous as a result of special experiences with plastic or for reasons of intentional industrial cooperations. In particular, the long-term experience is not sufficient for district heating suppliers. This point is dealt with in detail in section 4. In general, it can be said here that the main problem lies in the permeability of gases through plastics. Even if one regards oxygen diffusion into the heating water as a problem that was originally feared but which can be solved with today's designs, the scientific discussion is being fed as a result of the fact that even water vapour escapes. The supplier can only expect frictionless sale of his products when this question has been clearly answered and the new systems show advantages when composed with the proved building constructions.

A final decision on the advantages of competing materials polyethylene PE-X (formerly VPE) and polybutylene PB cannot be made. The decisive advantage of PB lies in its weldability which makes jointing easier. However, this advantage has disappeared since the mechanical jointing elements for PE-X are meanwhile regarded as reliable. The connecting strainers, available today, have been classified both by the user as well as the manufacturer as so reliable that they can be buried in the ground. Further developments on these connectors are no longer concentrated on a reliable function but on reducing costs by means of saving material and simplifying assembly.

2.3 Scope of the Task

The work presented here had the objective of describing the systems which are offered today and to present the status of development which they have achieved. Problems which still hinder an unconditional application should be outlined. A large part of this work is devoted to cost considerations which compare which laying costs would be incurred by a particular system in a particular country, see section 5.

In addition, this work includes a static consideration of the life of plastic medium pipes. This was needed because of the fact that system manufacturers were giving different load limits for the same pipe.

3. Description of the Pipe Systems

Five pipe systems are available on the European market today. The products are as follows in the order of their estimated position on the market:

1. Ecoflex	Manufacturer:	Oy Uponor Ab Ecoflex P.O. Box 21 SF-15561 Nastola
2. LR-Pex	Manufacturer:	Lôgstôr Rôr industri Danmarksvej 11 DK-9670 Lôgstôr
3. NTS-Ferwag-Flex	Manufacturer:	Brugg Kabel AG Rohrsysteme CH-5200 Brugg
4. Flexalen	Supplier:	Flexalen - Fernwârme systeme GmbH Kaiserstr. 45 A-1070 Vienna
5. Wirsbo - IM-RO-PEX	Supplier:	Wirsbo GmbH Max-Nonne-Str. 47 D-2000 Hamburg 62

Although the manufacturers named deliver their complete pipe system, they do not manufacture all components themselves. The medium pipes are sometimes purchased articles, as are pipe connections, welded fittings and other parts. The largest supplier of the medium pipe for the systems is Wirsbo. It supplies the PE-X pipe for the Ecoflex system, LR-PEX and Wirsbo IM-RO-PEX. It is the same product which is being used in great quantities in plumbing for hot-water pipes and underfloor heating.

In the following sections, the individual pipe systems will be described. This description should not replace the system details provided by the manufacturer, which can be found in the product catalogue, it should, however, present the most important characteristics of the system as required by district-heating specialists.

3.1 Ecoflex

3.1.1 Description

The Finnish product Ecoflex consists of a VPE medium pipe (manufactured by Wirsbo) with an EVAL oxygen barrier which is extruded onto the pipe. The pipe is contained in thermal insulation of foamed PE which is produced in layers. The jacket pipe is a corrugated PE-pipe, see Fig. 3.1-1.

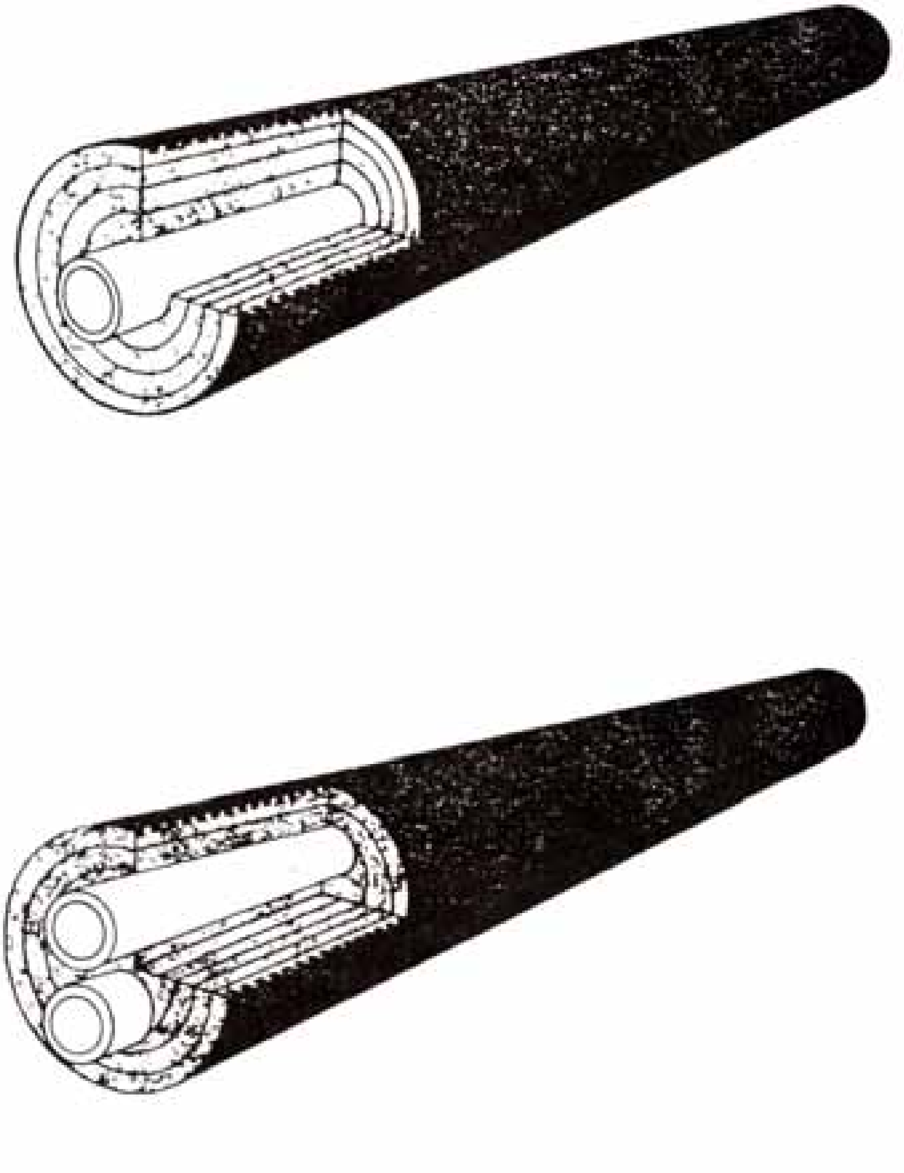


Fig. 3.1-1: Construction of the Ecoflex Pipe

The pipe material is supplied in rolls in nominal diameters of DN 20 to DN 80. A double pipe system, in which the supply pipe and the return pipe are enclosed in the same jacket pipe, is available for small pipelines of DN 20 to DN 40.

Pipe connections are made using clamp joints which are part of the Wirsbo pipe programme. Thermal insulation at the joints is ensured using insulating jackets. The whole joint is covered by a shrink sleeve between the ends of the jacket pipe, see Fig. 3.1-2. The metallic clamp joints can be combined with screw fittings so that branches, reductions and sharp pipe deflections can be included. There are special insulating components for these situations. Insulation is protected by special end caps at the front end so that, in the case of leakage, no water can enter the insulation layer.

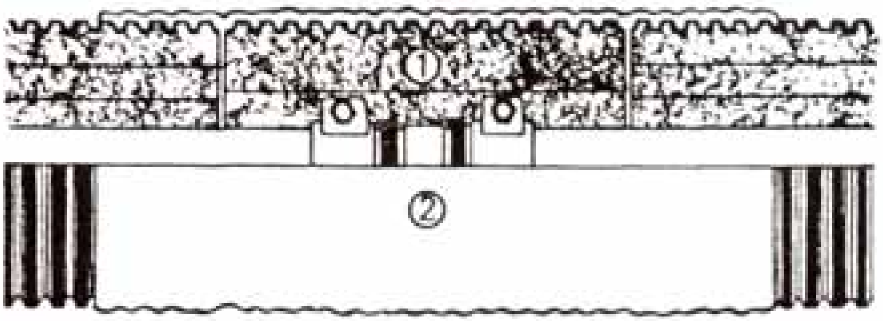


Fig. 3.1-2: Pipe Connection with Extra Thermal Insulation and Shrink Sleeves

Special components are small assembly shafts of polyethylene in which branches can be installed and protected from the earth, see Fig. 3.1-3.

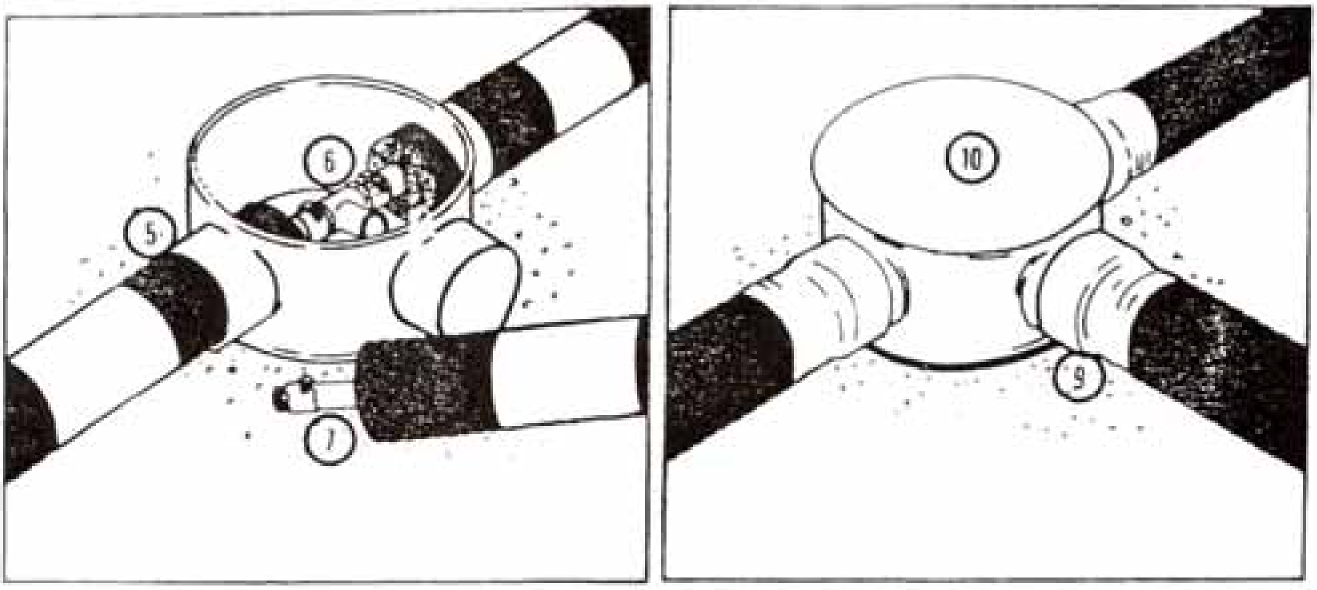


Fig. 3.1-3: Branch with Assembly Shaft

3.1.2 Limits of Application

Dimensions: Pipe material is supplied from DN 20 to DN 80 (int. dia. = 90 mm); double pipe from DN 20 to DN 40.

Standard delivery length is 200 m for DN 20 and 50 m for DN 80.

40 cm is required as minimum coverage, 80 cm for traffic loads.

The wallthickness of the jacket pipe is in correspondence to the diameter
for D = 128 1,3 mm
D = 160 1,8 mm
D = 200 2,2 mm

Loads: Stress and strain limits are not given exactly by the manufacturer. A limiting temperature of 90 °C for constant loads was men-tioned with a temporary overload of 120 °C. The corresponding maximum pressure is not given. At a constant temperature of 90 °C this should be 5 bar. (In a Finnish Ecoflex-brochure maximum pressures of 6 bar/ 90 °C and 10 bar/ 70 °C are given!)

3.1.3 State of Development

The Ecoflex system, in its present form, has alredy been used for 6 years. The diffusion barrier of EVOH (trade name EVAL) reduces the oxygen diffusion to about 1 % compared with the unprotected pipe. The present EVOH layer has been used for about two years. It is thinner and mechanically more stable than the previous brown barrier layer.

In Finland, about 60 km of plastic medium pipe constructions in general have been laid in public supply systems. 30 km of this is Ecoflex-pipes with about 15 km installed in Lahti. The long-term operational experience which has neen made there with PE-X medium pipes has led to a positive assessment of the Ecoflex design.

The clamp screwed fittings used as pipe joints have proved to be so reliable after up to 20 years of operation, that they can be buried directly in the ground.

The next objective of development work is to rationalize the production by a continuous foaming of the thermal insulation which today is being produced separately. In this way the layers of insulation could be replaced by a homogeneous foam layer.

3.2 LR-PEX

3.2.1 Description

The Danish pipe system LR-PEX from the manufacturer Lögstör Rör uses the PE-X medium pipe from Wirsbo, which has already been mentioned. It also uses the same diffusion barrier EVOH. The pipe construction corresponds more or less to that of plastic compound jacket pipes. The medium pipe is rigidly foamed with a polyethylene jacket pipe. A semi-flexible PUR-foam is used for the foam and LDPE is used for the outer jacket. In this way the pipes are at least suitably flexible in the case of small nominal diameters.

The pipes can be supplied in rolls for nominal diameters from DN 16 to DN 50. Pipes of DN 50 to DN 80 are supplied in lengths. There is only a single pipe system.

There is an extensive range of articles in the programme for pipe joints. Lines available are screwed clamp fittings and press-on joints for quick assembly. All PE-joints are also available with screw threads, so that they can be combined with metallic parts of the pipeline, such as T-branches, reductions and also with fittings.

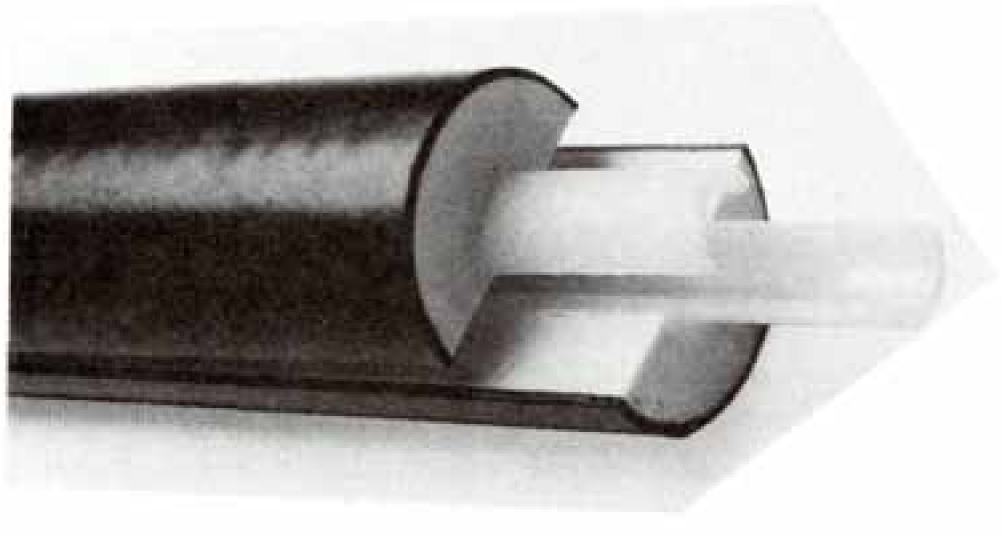


Fig. 3.2-1: Construction of the LR-PEX Pipe

The screwed clamp joints correspond to the types found on the market and do not need to be described here in more detail. However, the press-on connections are new, see Fig. 3.2-2. They are mounted using a special tool. It is a fast assembly process requiring no screws.

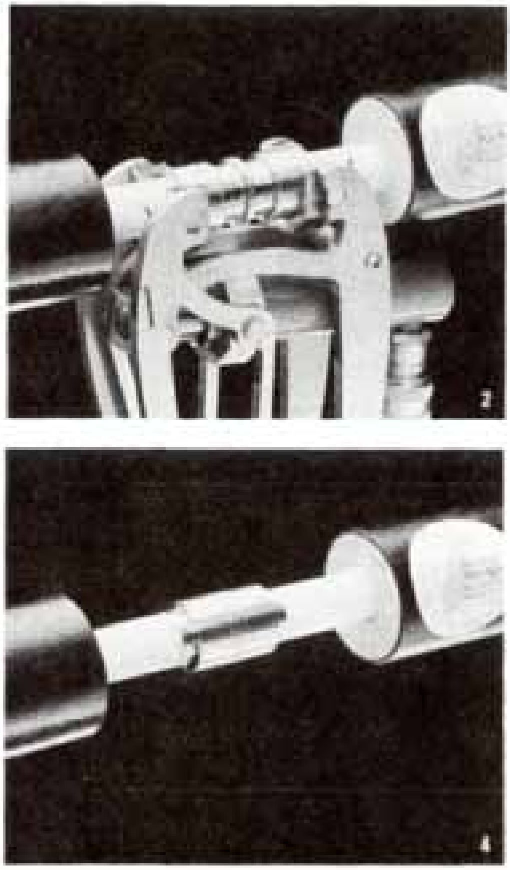


Fig. 3.2-2 Installation of the Press-On Joint

There are several possible ways to implement branches in the PE-X system. Figure 3.2-3 shows a selection. The various designs are allocated to particular ranges of the nominal diameter.

Joints in thermal insulation and in the jacket pipe are carried out with insulating foam and shrink sleeves. There is also a double leak-proof sleeve. At the front end the LR-PEX pipe is closed with end caps.

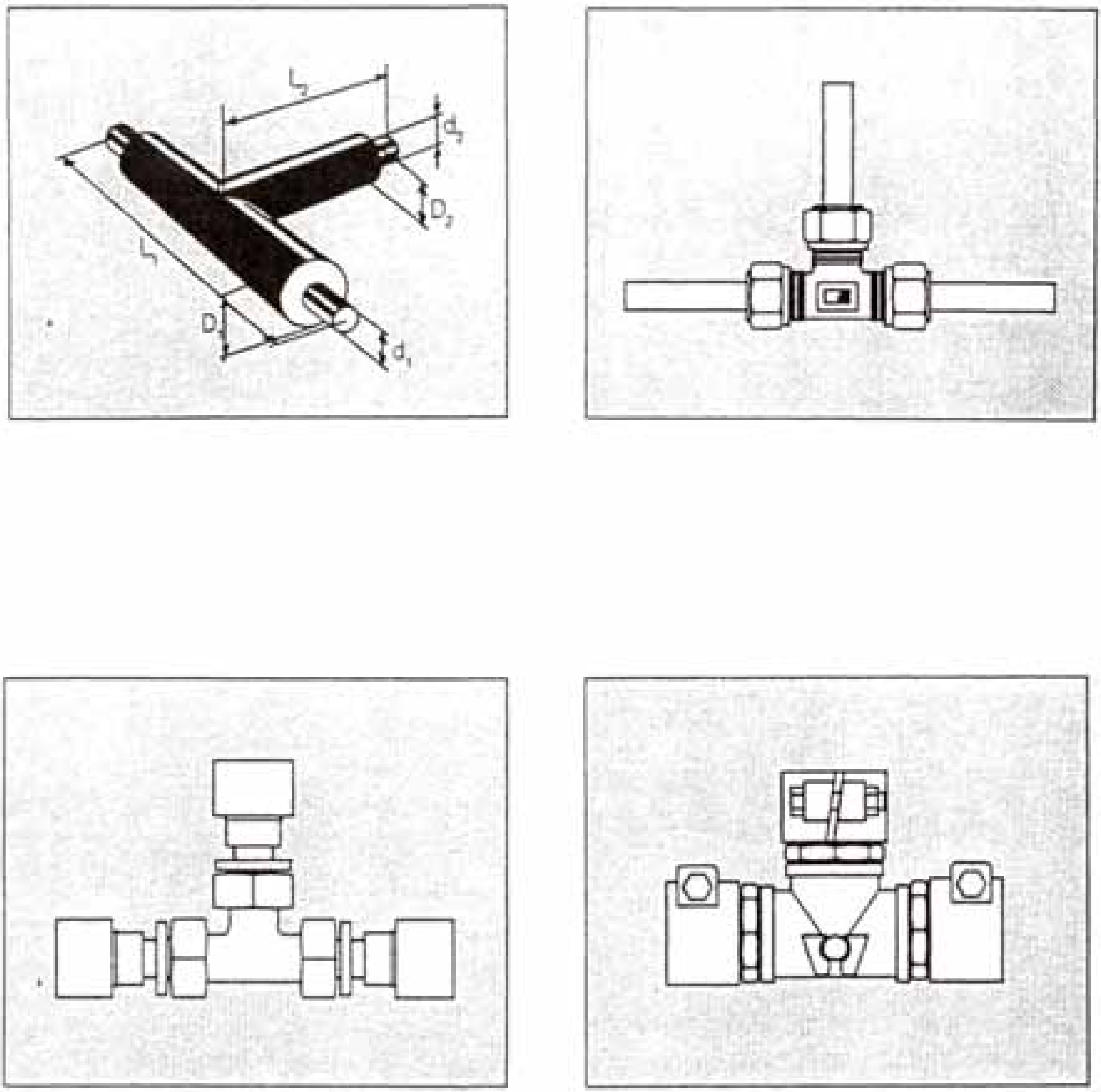


Fig. 3.2-3: Design of T-Branches

3.2.2 Limits of Application

Dimensions: Pipe material is supplied from DN 16 to DN 80 (int. dia. = 90 mm).

Delivery length is maximum 200 m for DN 16 and 50 m for DN 50.

Larger pipes of DN 50 and more are supplied in lengths of 12 m.

The wallthickness of the jacket pipe is for the outer diameter

66 to 90 mm	2,2 mm
110 to 125 mm	2,5 mm
140 to 180 mm	3,0 mm

Loads: Maximum values for temperature (constant temperature) and pressure are given as

$T = 95$ °C
$p = 6$ bar.

40 cm is required as minimum coverage.

3.2.3 State of Development

Lögstör Rör, as the largest manufacturer of plastic compound jacket pipes, has extended its programme of plastic pipe systems over many years with increasing success. Up to a few months ago, Lögstör was producing two systems, one based on PE-X and the second using the pipe material PB. Today the PE-X system alone has been preferred and this is also based on the Wirsbo PEX-pipe. Components for the PB system are only being maintained for customers involved in extension and completion work.

The programme of jointing elements is extensive in order to be able to offer favourable material for the different applications. The special components for jointing plastic compound jacket pipes with steel pipes to elements for PEX-pipes makes the connection of one system to the other easier.

Oxygen diffusion is limited by the EVAL-barrier of the Wirsbo PEX pipe. Water vapour diffusion is being investigated by Lögstör Rör in a cooperation with the Dansk Teknologisk Institut. The first qualitative results are available [3] and signify that the problem can be solved by adapting the design. Lögstör Rör has indicated that more explanatory statements will be available when the investigations have been completed in summer 1992.

3.3 NTS-Ferwag-Flex

3.3.1 Description

The NTS pipe is a new development of the Swiss cable manufacturer, Kabelwerke Brugg. It is a compound pipe with a special layer construction, which includes two diffusion barriers, see Fig. 3.3-1. The medium pipe consists of unblocked PE. This is enclosed in aluminium foil which overlaps and is glued together and acts as a diffusion barrier to water vapour. A textile band,under pre-tension, is wound around the aluminium foil to support it. The next layer is a flexible PUR foam as thermal insulation. This is surrounded once more by aluminium foil acting as a diffusion barrier. This is glued along its length and, during production, serves as a casing for the foam. The external protection of the whole structure is provided by a final extruded PE-jacket. The outer aluminium foil is declared as an oxygen barrier by the manufacturer.

The pipe material is available for nominal diameters of DN 20 to DN 65. A double pipe system for DN 25 and DN 32 can also be supplied. The pipe is either delivered in bundles of 50 or 100 m lengths or on a cable drum.

The PE-X medium pipes are screwed together using clamp joints. Shaped pieces are used to insulate the joints. The connection of jacket pipes is made using a slip-on sleeve and shrink socket, see Fig. 3.3-2.

As in the case of plastic jacket pipe systems, manufactured tees are available for constructing branches, see Fig. 3.33. At pipe ends, the front end of the PUR-foam is closed using end caps of shrink-on material.

The supply programme for the NTS-system is being continually extended. The production volume amounts to about 15 km per year. The manufacturer has made his design particularly safe regarding the diffusion of oxygen and water by using two diffusion barriers.

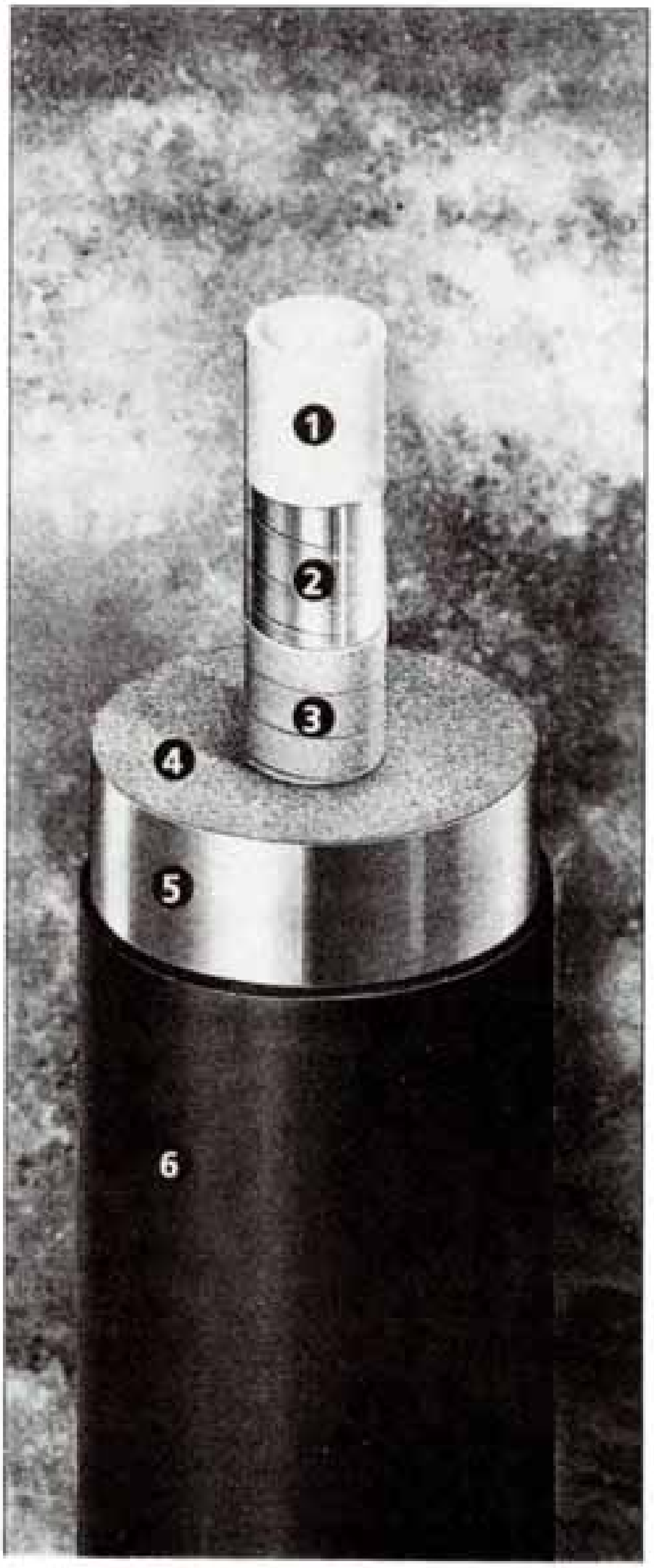


Fig. 3.3-1: Pipe Construction of the NTS-Ferwag Flex

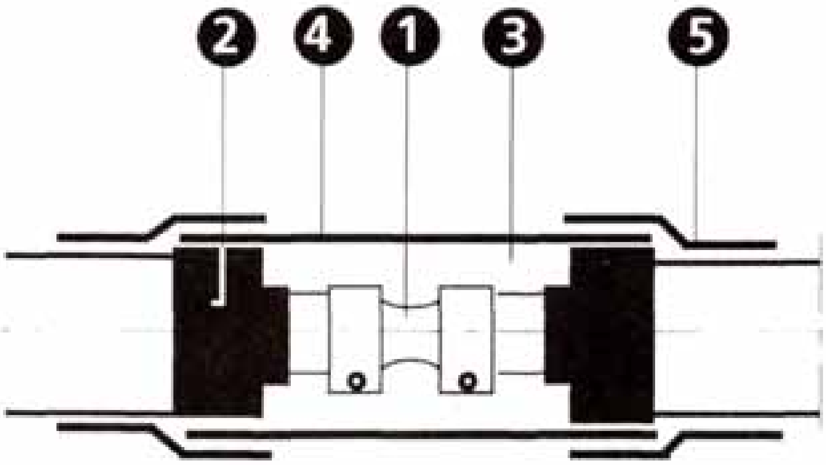


Fig. 3.3-2 NTS-Ferwag Flex Pipe Connection Laid in the Ground

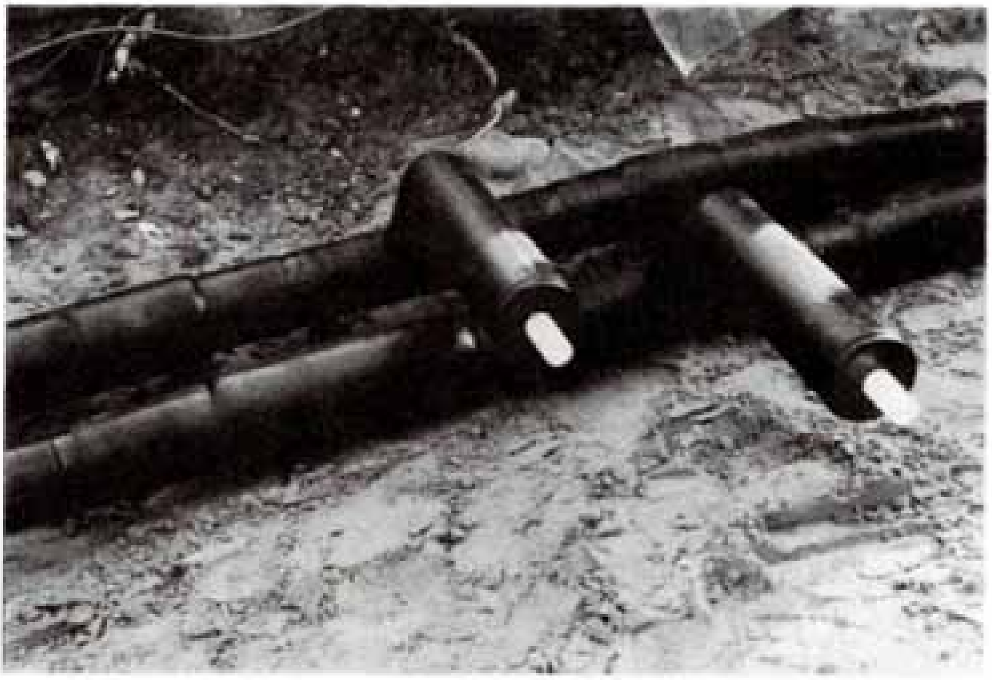


Fig. 3.3-3 Branch with Manufactured Tees

3.3.2 Limits of Application

Dimensions: Pipe material is supplied in 4 nominal diameters from DN 20 to DN 65, double pipes are available for DN 25 and DN 32.

Delivery lengths in bundles is 50 m or 100 m. Lengths of 500 m are available on cable drums.

The thickness of the outer PE-jacket pipe is 3 mm.

Loads: The system can be subjected to a maximum constant temperature of

$T = 90\ °C$
$p = 6\ \text{bar}.$

60 cm is required as minimum coverage.

3.3.3 State of Development

The NTS-Ferwag system is a relatively new product, whose palette of products is still being continuously extended. In the meantime, pipes and accessories are available up to DN 65. The extension of the programme to include a double pipe system of DN 20 and shaped pieces for the connection of single to double pipe systems has already been announced.

According to the manufacturer, a particular development priority was to find a guarantee against uncontrolled diffusion processes. The NTS-system is the only pipe containing two metal diffusion barriers. The inner layer covers the medium pipe in a spiral envelopment, whereby only short pieces of pipe at joints are unprotected. The outer aluminium foil covers the foam in such a way that, together with the end caps on the front end, the PUR foam is completely isolated. Sleeves are also mounted without previously shrinking on end caps.

The NTS pipe was designed under particular consideration of diffusion flows of water vapour from the medium pipe into the PUR foam. This flow of material is not only to be observed it is also an important factor in the determination of the lifetime of the pipe. The end of the period of utilization is considered to be reached when the heat conductivity has increased by 30 % as a result of water in the thermal insulation. Section 6 deals with this topic in more detail.

A special aim of development activities of the NTS-manufacturer is the combination of the flexible system with horizontal drilling, so that laying is possible without digging trenches. Pipe laying using this technique is being offered by the manufacturer on his own and also in a cooperation with Flowtex.

3.4 Flexalen

3.4.1 Description

The Flexalen pipe is composed of three elements, as shown in Fig. 3.4-1. The medium pipe consists of the thermoplastic polybutylene. It lies in specially shaped, cylindrical insulating elements of PUR rigid foam, which are enclosed in a polypropylene envelope. The ends of the insulating elements are so shaped that they fit into each other to form a joint, as shown in the longitudinal section in Fig. 3.4-1. The whole arrangement is enclosed in a corrugated jacket pipe of HDPE. The pipe is easy to bend.

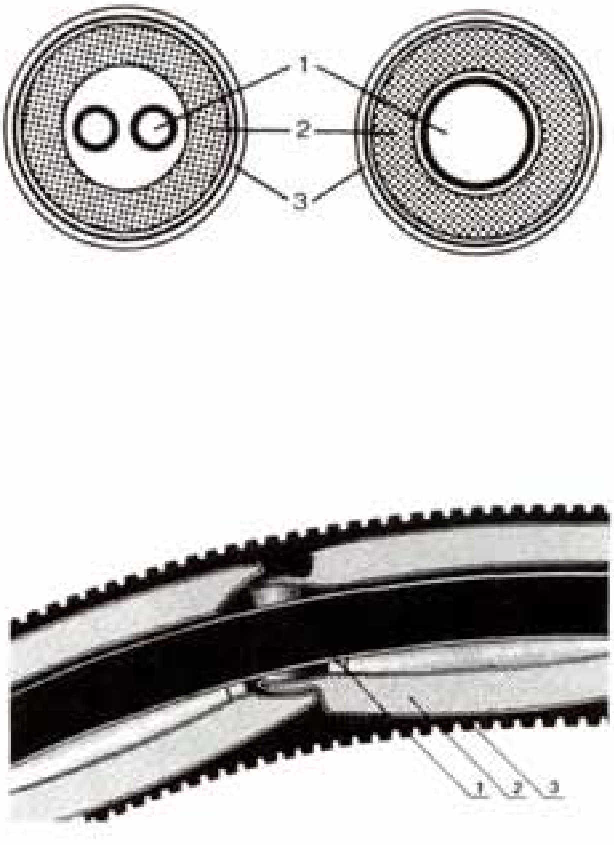


Fig. 3.4-1: The Flexalen Pipe System with Corrugated Jacket Pipe

The arrangement of the medium pipe may vary. For instance, instead of one large medium pipe both small medium pipes can be installed in the insulating elements. Supply and return pipes are then laid uninsulated with respect to one another side by side.

In addition to the corrugated pipe system, pipe lengths are available for nominal diameters of DN 80 (internal diameter = 90 mm) and DN 100 and these are, in principle, constructed similar to compound jacket pipes. They only allow bending radii of 18 m in opposition to 1,25 m for the corrugated pipe system.

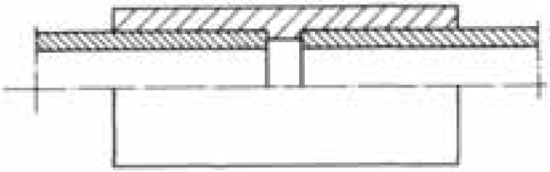
Welding is preferred for jointing medium pipes since PB is a thermoplastic. However, in addition, screwed clamps or flange joints can be used to make individual joints or for a connection of plastic to metal.

Hot-tool sleeve welding and hot-coil sleeve welding can be used as welding methods. Hot-tool butt welding is also applied for larger nominal diameters of DN 80 and DN 100, see Fig. 3.4-2, no. 3.

There are sleeve shaped pieces for jointing the jacket pipe of the corrugated pipe. These are fixed with bands after the front ends have been covered with end caps. Pipe lengths are connected with slip-on sleeves which is normal practice for compound pipes, only here the sleeves are fully foamed.

Changes in direction are possible by bending the whole pipe. However, formed pieces are also available for sharp bends. The programme is completed by further fittings for branches, reductions, end plugs etc.

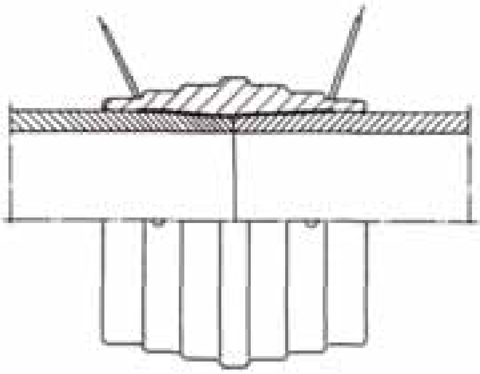
Up to now this system has not been fitted with a diffusion barrier.



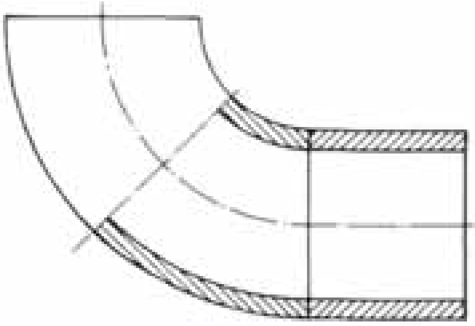
DN 20 to DN 80

1. Hot-Tool Sleeve Welding

DN 20 to DN 80



2. Hot-Coil Sleeve Welding



DN 80
DN 100

3. Hot-Tool Butt Welding

Fig. 3.4-2: Welding Processes for the Medium Pipe

3.4.2 Limits of Application

Dimensions: Pipe material is supplied from DN 20 to DN 80 (int. dia. = 74 mm) in corrugated jacket. DN 100 is available as lengths. Larger pipes can be ordered. A double jacket pipe system is available for DN 20 to DN 40, whereby the supply and return pipes come into contact.

Delivery lengths for single pipes up to DN 50 and double pipes up to DN 25 are 100 m, for larger pipes lengths of 50 m are available.

The wallthickness of the jacket pipe is about 2 mm.

Loads: Maximum combination of temperature and pressure is given as 90 °C for variable supply temperatures (60/90) and 6 bar.

0.5 m is required as minimum coverage, 0.8 m for traffic.

3.4.3 State of Development

The Flexalen system has undergone a development lasting about 8 years. It was designed in a close cooperation between a manufacturer of plastic pipes and a supply company. Polybutylene, of which the medium pipe is made, requires a special manufacturing technology, but this is available without restrictions. The PB pipe is standardized according to DIN. The producted quantities for PB are far lower than the quantities for PE, PP etc. For this reason there is only one producer in the EC.

The special advantages of PB pipes lie in its weldability, which makes the jointing technique easier. Proved welding processes and machines can be used which must be adapted to the behaviour of the material PB. Hot-coil sleeve welding is a technology developed in a cooperation with Georg Fischer, Schaffhausen, and is particularly suitable for use on the building site.

When comparing the Flexalen pipe with the PEX-pipe described earlier, it is noticed that no diffusion barrier for oxygen and water vapour is available. The manufacturer regards this danger as less serious. This is surprising since from literature it is well known that the coefficient of diffusion of oxygen in PB is of about the same order of magnitude as in PE [4]. The danger from water vapour, which could move outwards, seems to be less since hollow spaces are available within the chain of isolating elements. These elements may also not be damaged because each is protected by a thin envelope of polypropylene (PP). However, recently it became known that a diffusion barrier has also been developed for this system and it will soon be available.

3.5 Wirsbo - IM-RO-PEX

3.5.1 Description

The Swedish pipe manufacturer Wirsbo is offering a pipe system with the name IM-RO-PEX with a PE-X medium pipe. This has an oxygen barrier (EVAL) which is extruded onto the medium pipe.

The pipe system consists in principle of 2 parts:

1. Insulating element
2. PE-X medium pipe

The insulating element is composed of a corrugated HDPE jacket pipe, thermal insulation of compressed glass wool and an HDPE guide pipe. Each insulating element is fitted with special end caps of VPE. These end caps carry the guide pipe. The sealing between the end caps and the guide pipe is made using an O-ring and to the jacket pipe using molten butyl. At one end of the guide pipe there is a snap-on sleeve of PE welded which takes up the expansion movements of the guide pipe. The connection between two insulating elements is shown in Fig. 3.5-1. The gap which arises when the insulating elements are joined together is filled by a PEX foam disc. In addition a shrink sleeve is shrunk onto the jacket pipe to provide further protection.

The insulating jacket is first laid without the medium pipe. The PE-X medium pipe is later fed by hand or with a rope winch into the guide pipe.

Medium pipe connections are made with clamp couplings, see Fig. 3.5-2. A comprehensive programme of pipe connections are offered by Wirsbo so that branches, reductions, and 90° bends can be constructed without problems.

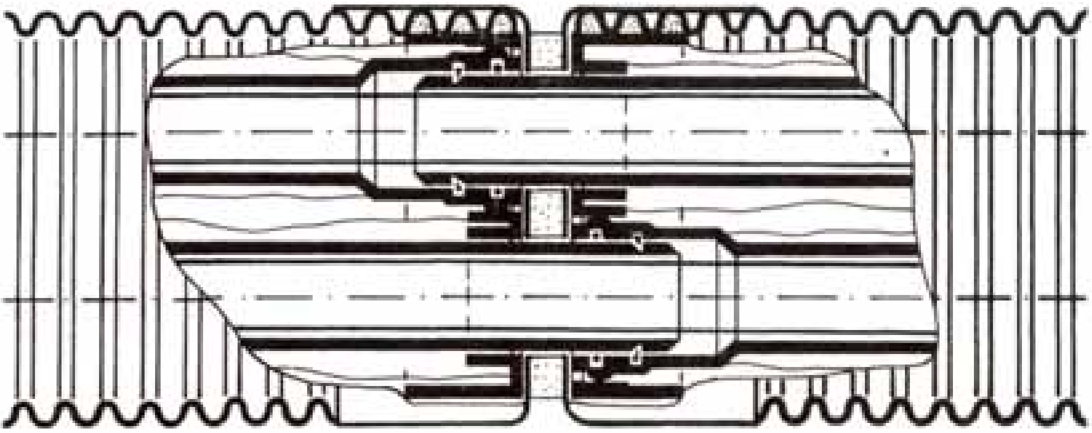


Fig. 3.5-1 Connection of Two Insulating Elements

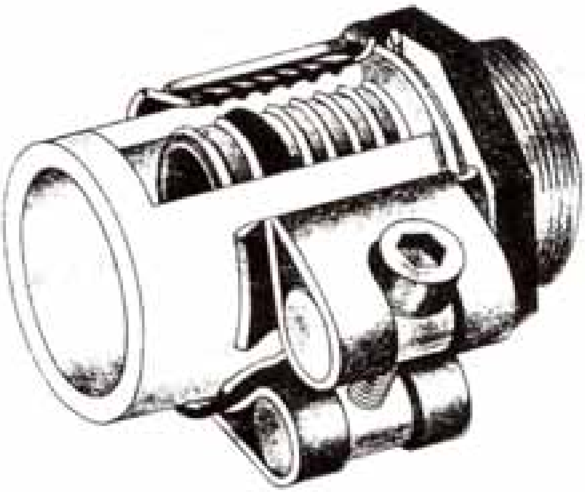


Fig. 3.5-2: Clamp Coupling for PEX Medium Pipe

3.5.2 Limits of Application

Dimensions: The PE-X medium pipe is supplied from DN 20 to DN 80 (int. dia. = 90 mm).

Double pipes are available from DN 20 to DN 40. The standard delivery length is 200 m; longer lengths can be obtained if required.

Delivery length of the insulating elements is 12 m.

The wallthickness of the jacket pipe depend on the diameter. It is
for D = 128 2,2 mm
D = 163 2,5 mm
D = 186 2,8 mm
D = 225 3,0 mm

Loads: The following constant temperatures and pressures are given as limits for application

T = 90 °C , p = 6 bar.
T = 70 °C , p = 10 bar.

According to information from the manufacturer 50 m minimum coverage is required in the area of roads and 70 cm for open spaces.

3.5.3 State of Development

Wirsbo is an important manufacturer of PE-X pipes for heating buildings and water pipes for plumbing and is a supplier for the pipe systems of Ecoflex and Lógstór. With its IM-RO-PEX system, Wirsbo is also offering a new plastic system for district heating pipelines of small nominal diameter.

Wirsbo has an insulating jacket that is separate from the medium pipe. The advantage of this pipe construction is that later the medium pipe can be changed without any expensive earthwork. A disadvantage is the extra expense and effort required in laying the pipe in the first place.

Numerous designs of connecting elements and formed pieces are available from the plumbing industry.

Oxygen diffusion has been reduced by the EVAL-barrier to such an extent that no damage to corrosion-prone components is to be expected.

However, overall, it must be said that the IM-RO-PEX system is not fully available on the market. It should be mentioned that experience from Sweden has been collected from several pilot applications. These were accompanied by a series of scientific investigations which were carried out in Studsvik. All results have been brought into the development of the IM-RO-PEX system.

4. General Situation from a Technical Point of View

Independent of particular questions which are presented by the individual systems described above, the general situation regarding the application of plastic medium pipes will be considered in the following sections. The behaviour, typical of plastics, of both pipe materials for the operational conditions found here allow a series of general statements to be made.

The annual quantity of pipe material produced for the region of Central and Northern Europe is estimated to be a maximum of 1000 km pipeline (double pipe). Of this, only about 10 % is used in networks for community district heating supply. The main part is probably used in the construction of small networks or systems which are installed by fitters and plumbers.

Plastic medium pipes are not used on a wide scale in public district heating supply, but only by a few companies. Before individual questions on the behaviour of the materials and other development objectives are dealt with, in the following sections, details will be given of the laying practice for the systems described above.

4.1 Laying Practice

The main advantage of plastic pipe systems lies in the high performance of laying that can be achieved. The pipes are laid in a trench which can be kept narrow, without working space and can be so designed that it can pass by obstacles, see Fig. 4-1. Assembly times are predominantly determined by branches and joints so that most of the trench can be filled in immediately after laying the pipe. It is possible to lay pipes for complete housing estates within in few days.

Moreover, an important advantage for laying in the ground is the corrosion resistance of the pipes. Should a leak occur, there is no need to fear that the medium pipe will rupture. The thermal insulation becomes wet but supply is not disrupted. Naturally, the thermal insulation should only be allowed to become wet over as short a length of pipe as possible.

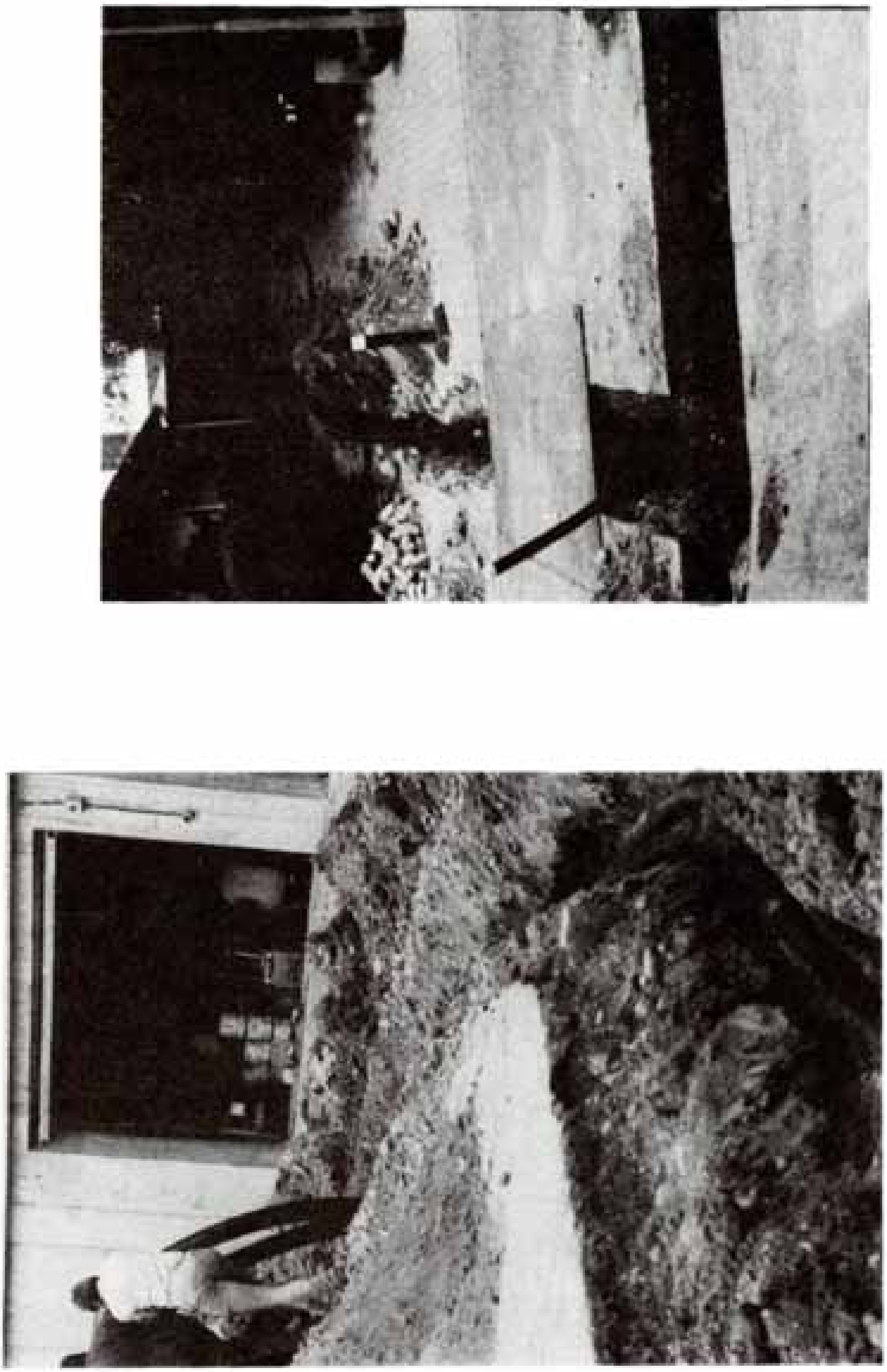


Fig. 4-1: Pipe Assembly of a House Connection

PE-X pipes are joined exclusively with screw clamps which are also sometimes used for joining PB pipes. Since a lifetime of 35 years is often required, these elements are considered with a certain amount of scepticism as a result of the well-known tendency of plastics to creep at higher temperatures. All information available points to the fact that jointing components normally used today are reliable. This experience has been deduced from up to 20 years of operation. Neither the manufacturers nor the operators have any reservations against laying connections underground.

Generally, it must be stated that, in comparison to proved systems with medium pipes of steel, suppliers are less experienced in laying and operating plastic pipe systems.

4.2 Oxygen Diffusion

District heat suppliers can rely on the results of developments in the field of underfloor heating and experience made there wth diffusion barriers. Three different strategies have been followed up to now by the manufacturers of the 5 products described above:

1. Separating the pipe with an extruded layer of EVOH (trade name EVAL), with a high resistance to diffusion, so that the oxygen diffusion is reduced to about 1/100;

   Manufacturer: Wirsbo and hence Ecoflex and Lögstör as well.

2. Separation with 1 or 2 metal foils

   Manufacturer: Brugg Kabel

3. No barrier

   Manufacturer: Flexalen

Today, it can be said that Flexalen is moving towards the first strategy so that the question "barrier yes or no?" will not be asked any longer.

Specialists of material testing reservedly assess the reliability of oxygen barriers as positive, e.g. [7]. However, further investigations requiring much effort are still being carried out since the effects of district-heating operating data cannot be reliably assessed. The first influence is the temperature. most investigations up to now have been carried out at 50 °C. Since the diffuse transport of materials follows an Arrhenius function, further measurements of the oxygen permeability up to 90 °C would be advisable.

Secondly, proof of the stability of the diffusion barrier is also required. Temperature changes can damage foil linings or perhaps the coatings as well. Furthermore, the stability of the coatings in a warm, damp atmosphere should also be checked. At present, special investigations for this are starting in Germany, whereby the manufacturers are also involved.

4.3 Water Vapour Diffusion

A danger to the pipeline as a result of water vapour which is forced outwards through the wall of the pipe was first noticed about two years ago. Due to the fall in temperature from the interior to the outside of the pipe, the water vapour condenses in the thermal insulation and could lead to a dangerous rise in the heat conductivity.

An influence on the system as a result of water vapour is seen to be less serious than as a result of oxygen. The most important reasons for this are that wetting has not yet been noticed in systems operated for many years, that dampness can hardly danger the function of the pipeline and that a certain rise in the heat losses is acceptable as long as investments for the system are low. However, calculations which show notable amounts of damp which escape through the pipe wall during one year of district-heating operating conditions, should not be ignored. Finally, one manufacurer (Kabel Brugg, see Section 3.3) even measured the lifetime of his system by means of this water permeability.

However, in comparing the systems regarding this danger, it becomes apparent that they must be very differently susceptible to this phenomenon. In insulation which is enclosed on all sides, the quantity of water will continue to rise with the period of operation, whereas in other systems certain quantities of water can be collected in the existing cavities perhaps without any damage, or the pipes are so arranged that water coming in can also go out again. These considerations are pure speculation and have not been checked by investigations. For this reason, systematic experiments are now starting in Germany. First quantitative results are already available from Denmark [3]: the system could be so designed that no water is collected in the insulation. This deduction has not yet been conclusively drawn from material published at present. Industry involved in the project (Lôgstôr) intends providing supplementary information when the present investigations are completed in summer 1992.

4.4 Behaviour of Materials when Using Friction Reducing Additives

Whereas district heating networks today are still exclusively operated with conditioned water, for the future there is a possibility of putting additives in the water. Additives reduce the pressure losses for the circulated water. Since, on the one hand, additives are surface active and, on the other hand, it is well known that surfactants can negatively affect the material properties of plastics, the question is whether problems are to be expected in this situation.

The tensides Dobon G and Habon G from Hoechst AG have proved successful in district heating networks up to now. Final, quantitative statements on the influence of these tensides on material characteristics cannot be made till the systematic tests have been completed. They started in Germany early 1992 [2] and will probably be completed at the end of the year or beginning of 1993. The pipe materials PE-X and PB are being tested as well as GF-UP for temperatures between 70 and 110 °C and pressures of about 6 bar.

First considerations, analyses of literature and comparison with similar applications allow a positive result from the experiments to be expected. It appears as though the pipe materials PE-X and PB are not damaged by friction-reducing additives at temperatures up to 90 °C [2].

On drag reduction there can shortly be expected a special report titled "Advanced Fluids" [10].

These expectations are in contradiction to shortly published Swedish results from Studsvik Energy [11].

Their first experiments have shown that Habon G reduces the strength of PE-X material and promotes brittle fracture.

4.5 Provisional Sealing of the Pipe by Squeezing

It is sometimes necessary to block off sections of a district heating network to be able to make new connections or to undertake maintenance work. The pipes are usually closed using shut-off valves. In the case of plastic pipelines of VPE or PB, the idea arose of provisionally closing the pipe by squeezing the medium pipe with an appropriate tool. In this way, the expensive fittings in the network, which require a lot of maintenance, are no longer required. From experience it has been found that squeezing the pipe does not lead to breakage, since plastic is very tough and deformable. However, it has not been decided whether on not the pipe is damaged too much by this process.

Squeezing is done with special tools. A decision on the admissibility can only be made when creep tests with squeezed pipes have been carried out. Manufacturers have been asked to do this. In addition, material tests will be carried out at a German testing institute in the second half of 1992.

It still has to be determined under which conditions squeezing can be allowed, i.e. pipe geometry (nominal diameter, wall thickness) and operating data (pressure, temperature). If necessary, supporting sleeves could be developed to mechanically take the load off a damaged pipe and to serve as a mark so that the medium pipe is not squeezed again in the same place.

4.6 Laying in Horizontal Bores

In recent years, plastic pipes have been successfully laid for gas pipelines using horizontal drilling techniques. This method seems to be promising for district heating pipelines particularly when the supply and return pipes are enclosed in the same jacket pipe and laying lengths are not too long.

The main problem is the handling of the tension when the pipe is pulled into the drilled tunnel, because plastic pipes can only withstand relatively low longitudinal forces. Systems with corrugated jacket pipes are unsuitable for being pulled into position.

It is logical that Kabel Brugg is making particular efforts in this pulling-in technique because the NTS-Ferwag system has an increased longitudinal strength as a result of the metal lining.

Kabel Brugg is cooperating with Flowtex to form a service. The Flowtex process is seen as suitable because the drill hole has a good sliding behaviour as a result of the bentonite used as flushing agent. The principle of the process is shown in Fig. 4-2.

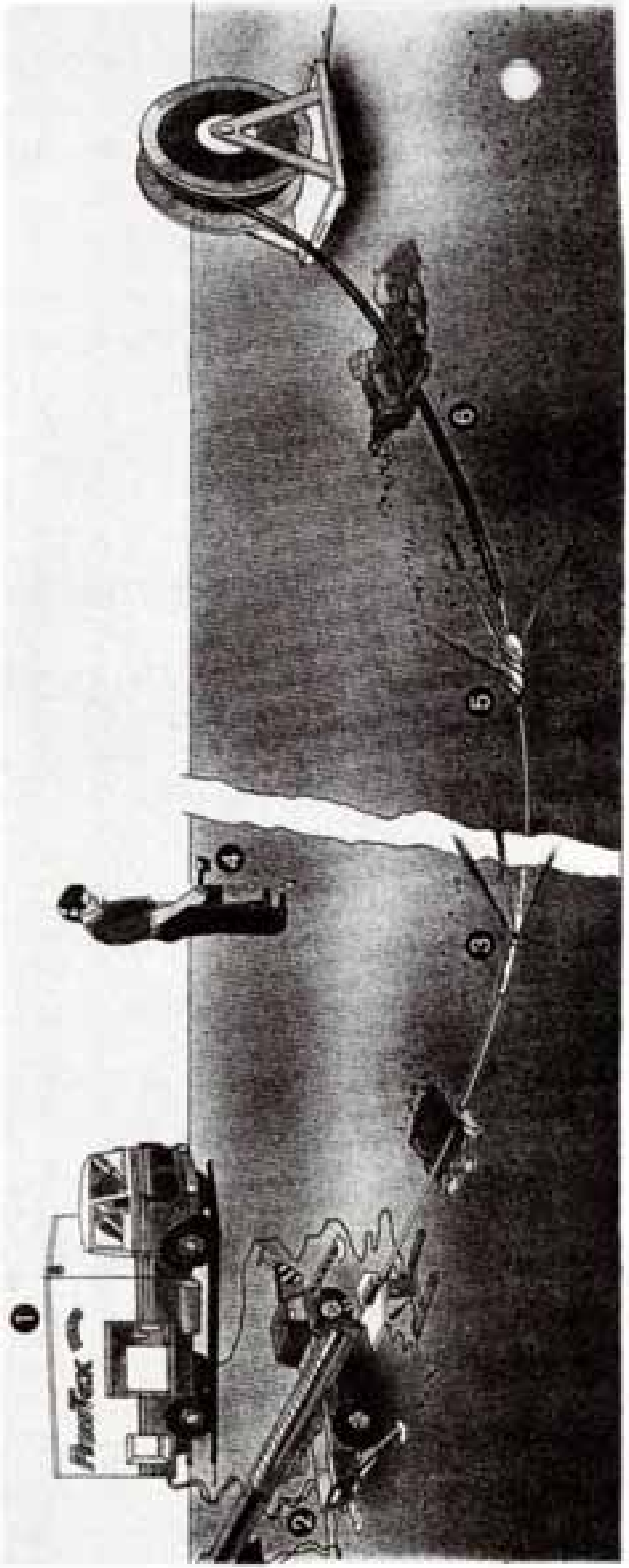


Fig. 4-2: Principle of the Flowtex Horizontal Drilling Process

5. Cost Situation for Plastic Systems in 6 European Countries

Laying costs of the 5 flexible pipe systems described will be determined in the following section and compared with those of today's standard plastic jacket pipe system (KMR). From the individual prices, construction costs of the systems have been calculated for each country considered and compared.

5.1 Procedure

Starting from a typical routine structure for the subdistribution, the individual construction prices were obtained from the manufacturing companies. The required trench dimensions were determined for each laying process and the earthwork quantities calculated. Together with the civil engineering prices in the countries involved, these gave the engineering costs specific to the system.

The cost calculation was based on the systematic used in an earlier IEA study [1] so that results of both tasks can be compared for plastic systems. The standard design with German prices was used for the reference system KMR.

The individual working steps to determine laying costs are:

1. Determination of a typical routine structure, to characterize the subdistributionm.

2. Collection of the prices of material of all important components of the laying system in the currency of the manufacturer.

3. Collection of the assembly prices and calculation of the necessary time required with the hourly rates.

4. Determination of the earthwork quantities using the cross-section of the trench required by the system.

5. Collection of the specific civil engineering prices in the countries considered.

The laying costs determined from the data given above are determined for each country considered. The laying costs worked out here offer a quantitative comparison between the pipe systems. Costs which are not dependent on a particular system, e.g. for planning, management of the site and buildings on the building site, have not been considered here, so that the actual laying costs are about 10 to 20 % higher.

5.2 Basic Costs

5.2.1 Routine Structure of the Subdistribution

The calculation of the costs for material, assembly and earthworks is carried out for a typical subdistribution network. This consists of straight lengths which are laid through open land and roads. In addition, changes in direction, branches and a coverage of 0.6 m over everything has been considered.

Components of the Routine Structure

Main Pipeline:

70 m pipeline	DN 25	in open land
30 m pipeline	DN 25	in area of roads
70 m pipeline	DN 40	in open land
30 m pipeline	DN 40	in area of roads
35 m pipeline	DN 80	in open land
15 m pipeline	DN 80	in area of roads

Branches:

5 branches	DN 25	to main pipe DN 40
5 branches	DN 25	to main pipe DN 25
Branch length	8 m	

Changes in Direction 90°:

2	DN 25
2	DN 40
1	DN 80

Changes in Direction 10 - 45°:

2	DN 25
2	DN 40
1	DN 80

Coverage: 0.6 m

In addition, the following parameters had to be determined for each laying process:

- number of axial joints
- cross-section of trench
- method of making service connections (looping or branch)
- effort required for compensators
- bridges over the trench

5.2.2 Specific Civil Engineering Costs in the Countries Involved

Table 5.2-1 shows the specific civil engineering costs obtained for the countries involved. These costs were given to us by individual supply companies and could vary regionally within the countries.

Table 5.2-1 Specific Civil Engineering Costs

		Denmark * = DKR	Germany * = DM	Finland * = FMK	Sweden * = SKR	Austria * = AS	Switzerland * = SFR
Excavation incl. edging and surface (bitumen cover 20 cm)	*/m^3		150,-	100,-	155,-	245,-	71,50
Spoil in open country	*/m^3		50,-	24,-	80,-	180,-	18,-
Lining (horizontal)	*/m^2		25,-	24,-	-	150,-	18,-
Filling	*/m^3		55,-	24,-	250,-	240,-	56,-
- new material (incl. delivery)							
- material from intermediate storage (incl. transport)	*/m^3		55,-	16,-	130,-	120,-	18,50
- material stored on the side	*/m^3		22,-	8,-	65,-	50,-	12,-
Remaking the surface	*/m^2		120,-	100,-	177,-	340,-	100,-
- 20 cm bitumencover							
- open country	*/m^2		15,-	16,-	60,-	45,-	5,-
Bridges for vehicles, 4 m^2	*/bridge		600,-	400,-	1650,-	400,-	150,-
Hourly wage for skilled workmen (incl. all surcharges)	*/h		60,-	100,-	250,-	340,-	66,-

5.2.3 Costs of Materials

Table 5.2-2 shows the material costs (in the currency of the country of manufacture) as given by the system manufacturer or the user for the components of the subdistribution network for this study. All prices quoted are without value-added tax incl. transport.

Table 5.2-2 Material Costs in Currency of the Respective Country

			ECOFLEX * = FMK	LOGSTÖR * = DKR	BRUGG * = SFR	FLEXALEN * = AS	WIRSBO * = SKR	KMR * = DM
Pipe	DN 25	*/m-length	89,-		68,-	575,-	196,-	48,-
	DN 40	*/m-length	127,-		152,-	770,-	271,-	58,-
	DN 80	*/m-length	391,-		214,40 5)	1700,-	610,-	95,-
Bend 90°	DN 25	*/fitting	1)		176,- 2)	2880,- 2) 4)	1)	65,-
	DN 40	*/fitting	1)		210,- 2)	3100,- 2) 4)	1)	75,-
	DN 80	*/fitting	1)		- 2)	3460,- 2)	1)	125,-
Axial Joint	DN 25	*/fitting	222,-		320,- 4)	2160,- 3) 4)	410,-	15,-
	DN 40	*/fitting	356,-		222,40	2300,- 3) 4)	955,-	18,-
	DN 80	*/fitting	892,-		361,60 5)	2330,- 3)	960,-	20,-
T-fitting	DN 25/25/25	*/fitting	374,-		310,40	2280,- 4)	800,-	190,-
	DN 40/40/25	*/fitting	550,-		615,20	2740,-	1500,-	205,-

1) Not necessary

2) This is normally carried out by bending. However formed pieces are available

3) Medium pipe joint with electric welding sleeves

4) Double pipe

5) DN 65, BRUGG has a max. DN 65 in its programme

5.2.4 Assembly Costs

Assembly costs of the components of the comparative networks are given in Table 5.2-3. The pipe manufacturers were asked to provide information on the costs for the flexible systems, but costs for the KMR system were taken as standard values from German engineering planning figures. Assembly costs were converted using the corresponding hourly wage for skilled workmen in the respective country into assembly times. In this way the assembly costs can be calculated without any inaccuracy as a result of currency conversion.

Table 5.2-3 Assembly Costs, Assembly Time (Man-Hours)

			ECOFLEX * = FMK	LOGSTÖR * = DKR	BRUGG * = SFR	FLEXALEN * = AS	WIRSBO * = SKR	KMR * = DM
Pipe	DN 25	*/m-length h/m-length	16,- 0,16 2)		5,- 0,07 3)	30,- 0,09	45,- 1) 0,18	46,- 0,77
	DN 40	*/m-length h/m-length	16,- 0,16 2)		7,- 0,1	45,- 0,13	50,- 1) 0,20	52,- 0,87
	DN 80	*/m-length h/m-length	23,- 0,23 2)		7,- 4) 0,11	100,- 0,29	62,- 1) 0,25	74,- 1,23
Bend 90°	DN 25	*/fitting h/fitting	-		-	1140,- 3) 3,35	-	40,- 0,67
	DN 40	*/fitting h/fitting	-		-	1380,- 3) 4,06	-	45,- 0,75
	DN 80	*/fitting h/fitting	-		-	960,- 2,82	-	55,- 0,92
Axial Joint	DN 25	*/fitting h/fitting	153,- 1,53 2)		104,- 1,58 3)	700,- 3) 2,06	-	95,- 1,58
	DN 40	*/fitting h/fitting	153,- 1,53 2)		71,- 1,08	820,- 3) 2,41	-	100,- 1,67
	DN 80	*/fitting h/fitting	184,- 1,84 2)		71,- 4) 1,08	960,- 2,82	-	130,- 2,17
T-piece	DN 25/25/25	*/fitting h/fitting	232,- 2,32 2)		132,- 2,00	1670,- 3) 4,91	-	55,- 0,92
	DN 40/40/25	*/fitting h/fitting	232,- 2,32 2)		132,- 2,00	2030,- 3) 5,97	-	65,- 1,08

1) incl. T-fitting and axial joint

2) Not available; values taken from 87 an adapted according to the price development of material costs.

3) Double pipe

4) DN 65

5.2.5 Cross-Section of the Trenches, Earthwork Quantities

For each pipe system, details of the required trench measurements were collected for the appropriate nominal diameter of the subdistribution network. The earthwork quantities could then be worked out for each laying process.

Figure 5.2-1 shows the construction of a trench for pipe laying. The figure will help to explain the points in Tables 5.2-4 a - f of the trench cross-section for the pipe systems.

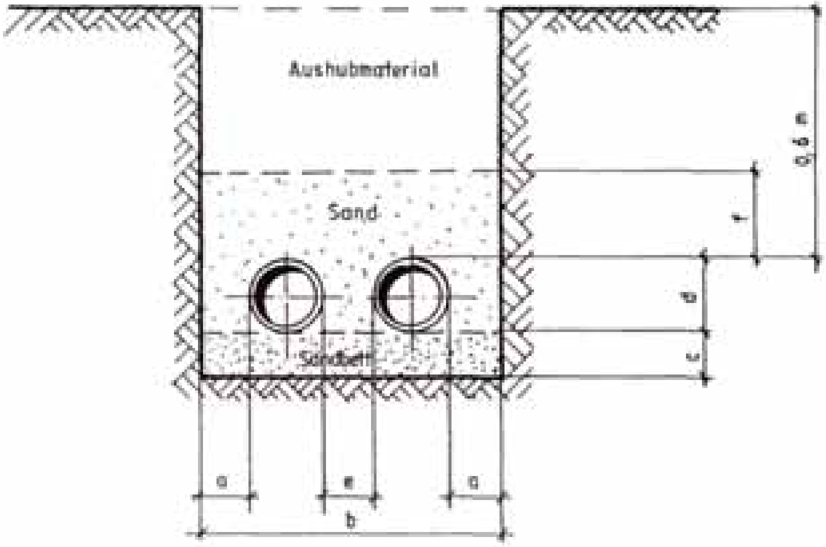


Fig. 5.2-1: Construction of the Trench for Pipe Systems Laid in the Ground

Table 5.2-4 a: Trench Cross-Section, Earthwork Quantities
ECOFLEX

		DN 25 2)	DN 40 2)	DN 80 3)
a	m	0,1	0,1	0,1
b	m	0,36	0,4	0,7
c	m	0,1	0,1	0,1
d	m	0,16	0,2	2 x 0,2
e	m	-	-	0,1
f	m	0,2	0,2	0,2
Spoil	m^3/m 1)	0.31	0,36	0,63
Transport of waste	m^3/m 1)	0,166	0,2	0,35
sand filling	m^3/m 1)	0,146	0,169	0,287
Filling with spoil	m^3/m 1)	0,144	0,16	0,28
Surface reconstruction	m^2/m 1)	0,36	0,4	0,7

1) per m-pipeline

2) Double pipe system

3) single pipe system

Table 5.2-4 b: Trench Cross-Section, Earthwork Quantities
LÖGSTÖR

		DN 25	DN 40	DN 80
a	m	0,1	0,1	0,1
b	m	0,46	0,52	0,66
c	m	0,1	0,1	0,1
d	m	2 x 0,077	2 x 0,11	2 x 0,18
e	m	0,1	0,1	0,1
f	m	0,1	0,1	0,1
Spoil	m^3/m 1)	0,36	0,42	0,58
Transport of waste	m^3/m 1)	0,13	0,16	0,25
Sand filling	m^3/m 1)	0,12	0,14	0,20
Filling with spoil	m^3/m 1)	0,23	0,26	0,33
Surface recontruction	m^2/m 1)	0,46	0,52	0,66

1) per m-pipeline

Table 5.2-4 c: Trench Cross-Section, Earthwork Quantities
BRUGG

		DN 25	DN 40	DN 65
a	m	0,1	0,1	0,1
b	m	0,52	0,55	0,55
c	m	0,1	0,1	0,1
d	m	2 x 0,11	2 x 0,125	2 x 0,125
e	m	0,1	0,1	0,1
f	m	0,1	0,1	0,1
Spoil	m^3/m 1)	0,42	0,51	0,51
Transport of waste	m^3/m 1)	0,16	0,18	0,18
Sand filling	m^3/m 1)	0,14	0,16	0,16
Filling with spoil	m^3/m 1)	0,26	0,33	0,33
Surface recontruction	m^2/m 1)	0,52	0,55	0,55

1) per m-pipeline

Table 5.2-4 d: Trench Cross-Section, Earthwork Quantities
FLEXALEN

		DN 25 2)	DN 40 2)	DN 80 3)
a	m	0,1	0,1	0,1
b	m	0,36	0,4	0,7
c	m	0,1	0,1	0,1
d	m	0,16	0,2	2 x 0,2
e	m	0,1	0,1	0,1
f	m	0,1	0,1	0,1
Spoil	m^3/m 1)	0,3	0,36	0,63
Transport of waste	m^3/m 1)	0,13	0,16	0,28
Sand filling	m^3/m 1)	0,11	0,13	0,25
Filling with spoil	m^3/m 1)	0,17	0,2	0,35
Surface recontruction	m^2/m 1)	0,36	0,4	0,7

1) per m-pipeline

2) Double pipe system

3) Single pipe system

Table 5.2-4 e: Trench Cross-Section, Earthwork Quantities
WIRSBO

		DN 25 2)	DN 40 2)	DN 80 2)
a	m	0,1	0,1	0,1
b	m	0,4	0,4	0,6
c	m	0,15	0,15	0,15
d	m	0,163	0,186	2 x 0,186
e	m	-	-	0,08
f	m	0,2	0,2	0,2
Spoil	m^3/m 1)	0,37	0,37	0,56
Transport of waste	m^3/m 1)	0,2	0,2	0,32
Sand filling	m^3/m 1)	0,2	0,2	0,29
Filling with spoil	m^3/m 1)	0,17	0,17	0,27
Surface recontruction	m^2/m 1)	0,4	0,4	0,6

1) per m-pipeline

2) Double pipe system

3) Single pipe system

Table 5.2-4 f: Trench Cross-Section, Earthwork Quantities
KMR

		DN 25	DN 40	DN 80
a	m	0,2	0,2	0,2
b	m	0,73	0,77	0,87
c	m	0,1	0,1	0,1
d	m	2 x 0,09	2 x 0,11	2 x 0,16
e	m	0,15	0,15	0,15
f	m	0,1	0,1	0,1
Spoil	m^3/m 1)	0,58	0,62	0,75
Transport of waste	m^3/m 1)	0,21	0,24	0,31
Sand filling	m^3/m 1)	0,20	0,22	0,27
Filling with spoil	m^3/m 1)	0,37	0,38	0,44
Surface recontruction	m^2/m 1)	0,73	0,77	0,87

1) per m-pipeline

5.2.6 Exchange Rates

The following table was used to convert the price of materials into the currency of the respective country. (Status in April 1992):

Currency		Rate
Danish Kroner	DKR	25.815
Finnish Marks	FMK	36.74
Austrian Shillings	AS	14.228
Swedish Kronor	SKR	27.615
Swiss Francs	SFR	109.780
Conversion Unit	DM	100.000

5.2.7 Factors which are Dependent on the System

In addition, other system specific factors are required to calculate the laying costs.

- Service Branches

In the case of flexible pipeline systems there exists the possibility to make service branches by the looping-in method. Supply and return pipes are laid in a curve from house to house.

Looping-in of the house connections is used in all flexible systems because looping-in appears to be cheaper than branches with tees. In this case the branch technique costs are calculated with 12 m length of pipe instead of 8 m branch length in the nominal diameter of the main pipeline.

- Number of Axial Joints (Sleeves)

Plastic medium pipe systems are normally delivered in long lengths, e.g. 100 m on a cabel drum, so that axial joints only occur in long pipelines. The case of subdistribution, considered here, with connections from house to house can virtually be completed without sleeves. Axial joints have been ignored in the cost calculations for flexible pipe systems.

A delivery length of 12 m is assumed for plastic jacket pipes. For the pipeline lengths and branches given here,

72 sleeves DN 25
52 sleeves DN 40 and
16 sleeves DN 80

are assumed for KMR.

- Effort Required for Compensators

In the case of plastic jacket pipes, additional compensating elements are required when laying the pipes. The costs for compensators has been calculated as 8 % of the direct construction costs compared with compensator-free laying of plastic medium pipes.

- Trench Bridges

In general pipe trenches for KMR remain open longer than those for plastic medium pipes. For this reason, one trench bridge per 100 m pipeline has been assumed.

5.3 Cost Comparison

A cost calculation was carried out for each pipe system and for each country involved taking into account the above mentioned basic data and the system specific factors.

The following laying costs are not intended for the calculation of the actual laying costs in a subdistribution network. The calculated laying costs are to be regarded as comparative costs in order to be able to assess comparatively the different systems from the different countries.
The civil engineering costs given here are also affected by relatively large uncertainties.

The costs for civil engineering were determined by making enquiries at only one address per country so that the data do not have to be representative of the country's average.

Material prices were given by the system manufacturer and were given in the currency of the country in question. Such prices are market prices and could be different in the different countries for the same product. Since not all systems considered are available on the market in all countries, calculations were made using the prices given in the country of the manufacturer and appropriately converted into the currency of the country concerned using the exchange rates.

The results of the cost calculations are given in the following tables, (Tables 5.3-1 to 5.3-6). A summary of the results is given in Table 5.3-7 in which the laying costs of the plastic medium pipe systems are presented as percentages of the reference plastic jacket system. The very low level of the Finnish product Ecoflex can partly be explained by the strong devaluation of the Finnmark in early 1992. In addition the Finnish District Heating association commented that the Finnish civil engineering costs and also assembly costs seen too low to be average values.

Table 5.3-1 Cost Comparison for Application in Denmark (all costs in DKR)

	ECOFLEX				LR-PEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-MARO-PEX				KMR			
	Material	Assembly	Civil Eng.	Total	Material	Assembly	Civil Eng.	Total	Material	Assembly	Civil Eng.	Total	Material	Assembly	Civil Eng.	Total	Material	Assembly	Civil Eng.	Total	Material	Assembly	Civil Eng.	Total
DN 25 Open Country																								
DN 25 Under Roads																								
DN 40 Open Country																								
DN 40 Under Roads																								
DN 80 Open Country																								
DN 80 Under Roads																								
Branches DN 25/25																								
Branches DN 40/25																								
Bend 90°, DN 25																								
Bend 90°, DN 40																								
Bend 90°, DN 80																								
Bend 10-45°, DN 25																								
Bend 10-45°, DN 40																								
Bend 10-45°, DN 80																								
Subtotal																								
Extra costs for comp.																								
Total																								

Table 5.3-2 Cost Comparison for Application in Germany (all costs in DM)

	ECOFLEX				IR-PEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-MARCH-PEX				KMR			
	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total
DN 25 Open Country	2288	672	2827	5788	4753	1218	3014	8985	5225	294	3515	9034	5727	378	2568	8673	3789	756	3446	7992	3360	3233	4871	11465
DN 25 Under Roads	980	287	3275	4544	2037	522	3820	6379	2239	125	4404	6770	2454	162	3134	5751	1624	324	3847	5795	1440	1385	6127	8953
DN 40 Open Country	3266	672	3277	7215	8512	1512	3515	13540	11680	420	4116	16217	7669	545	3048	11264	5239	840	3446	9526	4060	3654	5250	12964
DN 40 Under Roads	1399	287	3744	5432	3648	648	4404	8700	5005	180	5026	10212	3287	233	3646	7167	2245	360	3847	6452	1740	1566	6535	9841
DN 80 Open Country	5027	483	2850	8361	10329	1050	2438	13817	8237	231	2058	10527	8466	609	2710	11786	5896	525	2621	9043	3325	2583	3170	9078
DN 80 Under Roads	2154	207	3269	5630	4426	450	2954	7831	3530	99	2513	6142	3628	261	3209	7098	2527	225	2908	5660	1425	1107	3853	6385
Branches DN 25/25	1961	576	2423	4961	4074	1044	2583	7701	4479	252	3013	7744	4909	324	2201	7434	3248	648	2954	6850	3820	2400	2783	9003
Branches DN 40/25	2799	576	2808	6184	7296	1296	3013	11605	10011	360	3528	13900	6574	467	2613	9655	4491	720	2954	8165	3970	2496	3000	9466
Bend 90°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	260	160	0	420
Bend 90°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	180	0	480
Bend 90°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	110	0	360
Bend 10-45°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	260	160	0	420
Bend 10-45°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	180	0	480
Bend 10-45°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	110	0	360
Subtotal	19880	3762	24477	48119	45079	7740	25744	78563	50410	1962	28177	80550	42718	2982	23132	68832	29061	4398	26026	59486	24760	19328	35593	79681
Extra costs for comp.	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	25442
Total	-	-	-	48119	-	-	-	78563	-	-	-	80550	-	-	-	68832	-	-	-	59486	-	-	-	105123

Table 5.3-3 Cost Comparison for Application in Finland (all costs in FMK)

	ECOFLEX				IR-PEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-AARO-PEX				KMR			
	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total
DN 25 Open Country	6230	1120	1528	8878	12938	2029	1668	16636	14222	490	1937	16650	15589	630	1405	17625	10314	1260	1836	13411	9145	5390	2687	17223
DN 25 Under Roads	2670	479	2269	5419	5544	870	2695	9110	6095	209	3098	9403	6681	270	2193	9144	4420	540	2638	7599	3919	2309	4314	10543
DN 40 Open Country	8890	1120	1762	11772	23170	2520	1937	27628	31792	700	2228	34721	20876	909	1652	23438	14261	1400	1836	17497	11050	6090	2889	20030
DN 40 Under Roads	3810	479	2584	6874	9930	1080	3098	14108	13625	300	3504	17429	8947	390	2536	11873	6111	600	2638	9350	4735	2610	4592	11938
DN 80 Open Country	13685	805	1534	16024	28114	1750	1327	31191	22422	385	1114	23921	23045	1014	1464	25524	16050	875	1394	18319	9050	4305	1727	15082
DN 80 Under Roads	5865	345	2257	8467	12049	750	2061	14860	9609	165	1752	11526	9876	435	2227	12539	6878	375	1992	9245	3878	1845	2691	8415
Branches DN 25/25	5340	960	1310	7610	11089	1740	1430	14260	12191	420	1660	14271	13362	540	1204	15107	8840	1080	1574	11495	10397	4000	1535	15933
Branches DN 40/25	7620	960	1510	10090	19860	2160	1660	23681	27250	600	1910	29761	17894	780	1416	20090	12223	1200	1574	14998	10805	4160	1651	16616
Bend 90°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	707	268	0	975
Bend 90°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	816	300	0	1116
Bend 90°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	680	184	0	864
Bend 10-45°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	707	268	0	975
Bend 10-45°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	816	300	0	1116
Bend 10-45°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	680	184	0	864
Subtotal	54110	6270	14757	75137	122697	12900	15880	151477	137210	3270	17206	157686	116272	4970	14101	135343	79101	7330	15486	101917	67392	32214	22090	121696
Extra costs for comp.	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	42881
Total	-	-	-	75137	-	-	-	151477	-	-	-	157686	-	-	-	135343	-	-	-	101917	-	-	-	164578

Table 5.3-4 Cost Comparison for Application in Sweden (all costs in SKR)

	ECOFLEX				IR-PEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-MIKRO-PEX				KMR			
	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total
DN 25 Open Country	8287	2800	8026	19114	17210	5075	8323	30608	18919	1225	9681	29825	20737	1575	7119	29431	13720	3150	9915	26785	12165	13474	13482	39122
DN 25 Under Roads	3551	1199	5401	10152	7375	2175	5991	15542	8108	525	6919	15552	8887	675	4989	14551	5880	1350	6486	13716	5213	5774	9645	20633
DN 40 Open Country	11825	2800	9271	23896	30821	6300	9681	46802	42290	1750	11168	55208	27769	2274	8393	38437	18970	3500	9915	32385	14699	15225	14553	44477
DN 40 Under Roads	5068	1199	6187	12455	13209	2700	6919	22828	18124	750	7864	26738	11901	974	5811	18687	8130	1500	6486	16116	6299	6525	10334	23159
DN 80 Open Country	18203	2012	8035	28252	37397	4375	6692	48464	29825	962	5584	36372	30654	2537	7540	40733	21350	2187	7491	31029	12038	10762	8755	31556
DN 80 Under Roads	7801	862	5381	14045	16027	1875	4678	22581	12782	412	3932	17127	13137	1087	5168	19394	9150	937	4893	14981	5159	4612	6122	15894
Branches DN 25/25	7103	2400	6880	16383	14751	4350	7133	26235	16216	1050	8298	25564	17774	1350	6102	25226	11760	2700	8499	22959	13830	10000	7704	31534
Branches DN 40/25	10136	2400	7947	20483	26418	5400	8298	40116	36248	1500	9573	47321	23802	1949	7194	32946	16260	300	8499	27759	14373	10400	8316	33089
Bend 90°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	941	670	0	1611
Bend 90°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1086	750	0	1836
Bend 90°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	905	460	0	1365
Bend 10-45°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	941	670	0	1611
Bend 10-45°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1086	750	0	1836
Bend 10-45°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	905	460	0	1365
Subtotal	71976	15675	57131	144783	163211	32250	57717	253179	182516	8175	63020	253711	154664	12425	52318	219408	105220	18325	62186	185731	89645	80535	78913	24093
Extra costs for comp.	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	96162
Total	-	-	-	144783	-	-	-	253179	-	-	-	253711	-	-	-	219408	-	-	-	185731	-	-	-	345255

Table 5.3-5 Cost Comparison for Application in Austria (all costs in AS)

		ECOFLEX				LR-PEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-IAM-RO-PEX				KMR			
		Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total
DN 25	Open Country	16085	3808	8926	28819	33404	6901	9534	49840	36721	1666	11088	49475	40250	2142	8085	50477	26630	4284	10997	41911	23612	18326	15438	57376
DN 25	Under Roads	6893	1631	7616	16141	14316	2958	8859	26133	15737	713	10172	26624	17250	918	7236	25404	11412	1836	8974	22223	10119	7853	14208	32181
DN 40	Open Country	22952	3808	10315	37076	59823	8568	11088	79479	82084	2380	13009	97473	53900	3093	9576	66570	36820	4760	10997	52577	28531	20706	16607	65844
DN 40	Under Roads	9836	1631	8662	20131	25638	3672	10172	39483	35178	1020	11437	47636	23100	1326	8346	32772	15780	2040	8974	26794	12227	8874	15140	36242
DN 80	Open Country	35332	2737	8952	47022	72588	5950	7650	86189	57891	1309	6504	65704	59500	3450	8568	71519	41439	2975	8277	52692	23366	14637	10001	48004
DN 80	Under Roads	15142	1173	7548	23864	31109	2550	6765	40424	24810	561	5718	31090	25500	1479	7383	34362	17759	1275	6748	25783	10014	6273	8867	25154
Branches	DN 25/25	13787	3264	7651	24702	28632	5916	8172	42720	31475	1428	9504	42407	34500	1836	6930	43266	22823	3672	9426	3523	26844	13600	8822	49266
Branches	DN 40/25	19673	3264	8841	31779	51277	7344	9504	68125	70357	2040	11150	83548	46200	2652	8208	57060	31560	4080	9426	45066	27898	14143	9490	51532
Bend	90°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1827	911	0	2738
Bend	90°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2108	1020	0	3128
Bend	90°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1756	625	0	2382
Bend	10-45°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1827	911	0	2738
Bend	10-45°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2108	1020	0	3128
Bend	10-45°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1756	625	0	2382
Subtotal		139704	21318	68514	229537	316789	43860	71746	432395	354258	11118	78586	443962	300200	16898	64332	381430	204228	24922	73821	302971	173998	109527	98575	382101
Extra costs for comp.		-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	135570
Total		-	-	-	229537	-	-	-	432395	-	-	-	443962	-	-	-	381430	-	-	-	302971	-	-	-	517672

Table 5.3-6 Cost Comparison for Application in Switzerland (all costs in SFR)

	ECOFLEX				IRPEX				NTS-FERWAG-FLEX				FLEXALEN				WIRSBO-IMRO-PEX				KMR			
	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total	Material	Assembly	Civil Eng	Total
DN 25 Open Country	2084	739	1442	4266	4329	1339	1460	7129	4760	323	1702	6785	5217	415	1260	6893	3451	831	1813	6096	3060	3557	2375	8993
DN 25 Under Roads	893	316	2146	3356	1855	574	2520	4949	2040	138	2891	5070	2235	178	2052	4466	1479	356	2516	4352	1311	1524	4038	6874
DN 40 Open Country	2975	739	1670	5384	7754	1663	1702	11120	10640	462	1991	13093	6986	600	1495	9082	4772	924	1813	7509	3698	4019	2568	10286
DN 40 Under Roads	1275	316	2439	4031	3323	712	2891	6928	4560	198	3247	8005	2994	257	2364	5615	2045	396	2516	4957	1584	1722	4299	7607
DN 80 Open Country	4579	531	1444	6555	9409	1155	1186	11750	7504	254	995	8753	7712	669	1352	9734	5371	577	1363	7312	3028	2841	1555	7425
DN 80 Under Roads	1962	227	2126	4317	4032	495	1918	6446	3216	108	1623	4948	3305	287	2087	5679	2302	247	1893	4442	1298	1217	2514	5029
Branches DN 25/25	1787	633	1236	3656	3711	1148	1251	6111	4080	277	1459	5816	4471	356	1080	5908	2958	712	1554	5225	3479	2640	1357	7476
Branches DN 40/25	2550	633	1431	4615	6646	1425	1459	9531	9120	396	1707	11223	5988	514	1281	7784	4090	792	1554	6436	3616	2745	1467	7829
Bend 90°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	236	176	0	413
Bend 90°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	273	198	0	471
Bend 90°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	227	121	0	349
Bend 10-45°, DN 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	236	176	0	413
Bend 10-45°, DN 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	273	198	0	471
Bend 10-45°, DN 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	227	121	0	349
Subtotal	18108	4138	13937	36184	41063	8514	14390	63967	45920	2158	15618	63696	38912	3280	12972	55165	26472	4837	15023	46333	22554	21261	20175	63990
Extra costs for comp	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-	24515
Total	-	-	-	36184	-	-	-	63967	-	-	-	63696	-	-	-	55165	-	-	-	46333	-	-	-	88506

Table 5.3-7 Laying costs of the flexible systems as percentages of the costs of the reference KMR system

	ECOFLEX	IR-PEX	NTS-FERWAG-FLEX	FLEXALEN	WIRSBO-HM-RO-PEX	KMR
Denmark						
Germany	46	75	77	66	57	100
Finland	46	92	96	82	62	100
Sweden	42	73	74	64	54	100
Austria	44	84	86	74	59	100
Switzerland	41	72	72	62	52	100

6. Consideration of the Lifetime of Pipes of PE-X and PB

6.1 Definition of the Problem

Since the system manufacturers give different limiting loads for their pipe material to some extent, even though they use the same pipe material, a consideration of the lifetime of the materials used was undertaken.

The investigation intended to determine what lifetime is to be expected from straight pipes (without connections and formed pieces) when typical operating conditions for district heating networks of a variable 90/65 °C prevail. Only tangential stress from the internal pressure is considered for a given temperature collective. Other loads such as bending stresses and prevented heat expansion are subject to relaxation whose influence is not yet sufficiently well-known for district heating pipelines.

The main difficulty lay in the fact that there is little information available on the long-term behaviour of PE-X and PB which can be collected together in order to achieve a comparison with plausible assumptions. The creep curves of the relevant DIN standards do not include the steep decline which is characteristic of plastics as a result of ageing.

Although other investigations include these phenomena, the published creep curves are average value curves and not minimum value curves as required for dimensioning district heating pipelines.

The concept here envisaged first investigating only the effects of thermal loads on ageing. For this the creep curves from internal pressure tests were evaluated and from them lifetime curves formed. From the proportion of damage of the assumed temperature distribution the expected lifetime was determined according to an accumulation of damage hypothesis (Miner's Law).

In a second consideration, the lifetime which could be forecast from the simultaneous mechanical and thermal loads was determined. For this, the extrapolated creep curves of the DIN standards were used, which do not include the steep decline which is to be expected as a result of ageing. This procedure is admissible since the question of ageing was dealt with in the first stage and here only a control on how long the lifetime could be, without considering ageing, was undertaken.

6.2 Basic Information

The work was based on the present state-of-the-art and knowledge. DIN-standards were explicitly taken into consideration. Creep curves for the materials PE-X and PB are given in DIN 16892 and DIN 16968 and these do not have the steep decrease which is to be expected as a result of ageing.

Although it states quite clearly in DIN 16892 that sufficiently cross-linked polyethylene, as opposed to other known poly olefines, does not have a bend in the creep curve, experts such as the authors of [8] expect a steep decrease in the creep curves both for PB as well as for PE-X.

In Sweden, numerous inner pressure creep tests were carried out on pipes of PE-X and PB [8] and [9]. For both materials the expected sharp decrease was found as a result of ageing. The Swedish publications have two disadvantages for the application here:

- they are not comparative investigations between PE-X and PB but two separate activities
- no minimum values were given, only average values.

In spite of these limitations, the Swedish work is certainly the most comprehensive of all modern investigations of this subject and, for this reason, the lifetime curves were based on these results.

6.3 Assumed Loads

A temperature distribution according to Table 6.1 was assumed.

Supply Temperature [°C]	Hours per Year [h/a]
65	7110
66 - 70	800
71 - 75	500
76 - 80	250
81 - 90	100

Table 6-1: Assumed Temperature Distribution

Figure 6-1 presents this assumed temperature distribution as a block diagram.

The maximum operating pressure assumed was

$$p = 5 \text{ bar} = 0.5 \text{ N/mm}^2.$$

For typical wall thicknesses of district heating pipelines of PE-X and PB for the different nominal diameters one obtains from Figure 6-2 and

$$\sigma_{t(p)} = \sigma_{yp} = p \cdot d_i/(2 \cdot s)$$

the tangential stress according to Table 6-2.

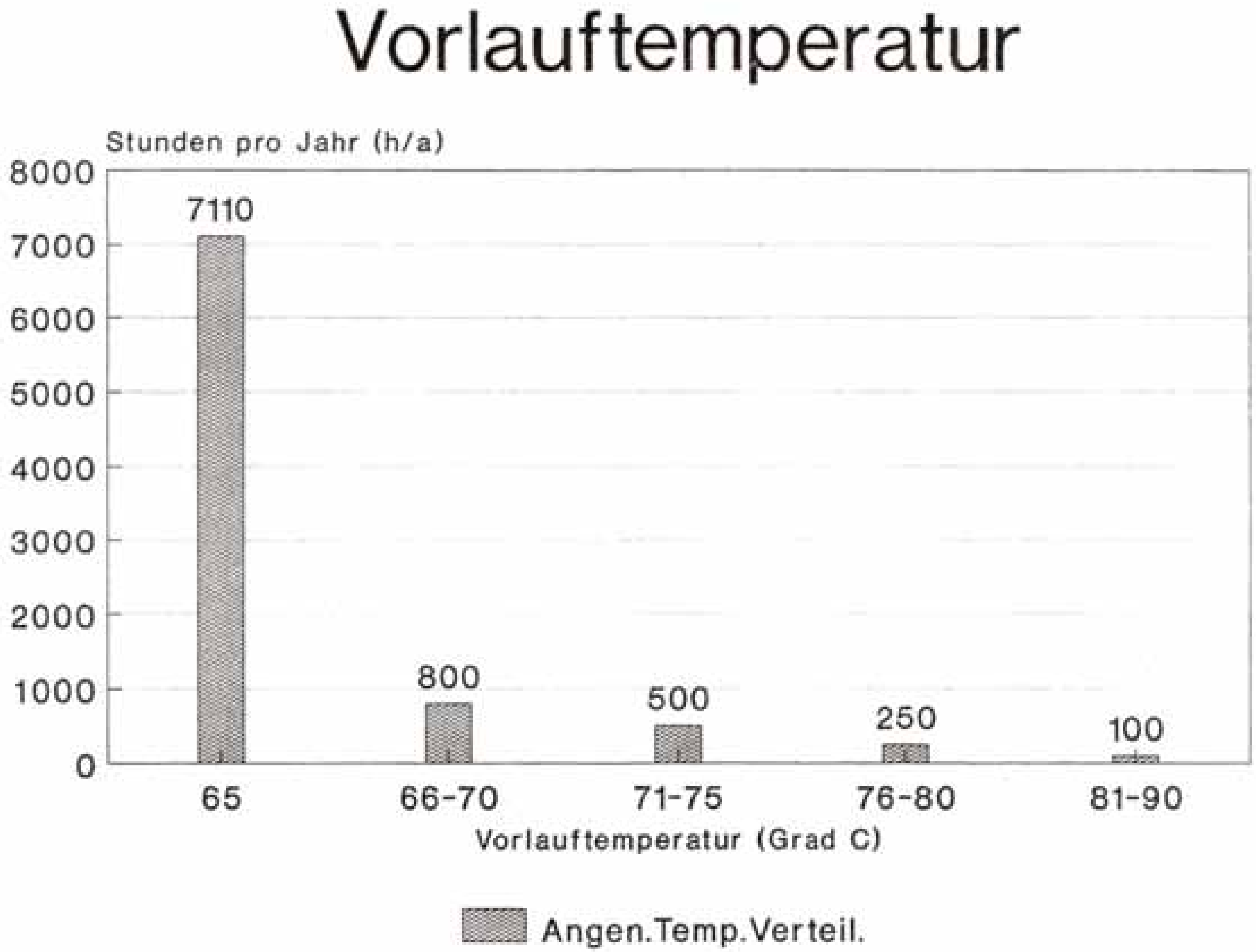


Figure 6-1: Assumed Temperature Distribution

DN [-]	d_a [mm]	s [mm]	d_i [mm]	$\sigma_{t(p)}$ [N/mm^2]
20	25	2.3	20.4	2.22
25	32	3.0	26.0	2.17
32	40	3.7	32.6	2.20
40	50	4.6	40.8	2.22
50	63	5.8	51.4	2.22
65	75	6.9	61.2	2.22
80	90	8.2	73.6	2.24

Table 6-2 Resulting Tangential Stress for an Internal Pressure of 5 bar

Other loads such as bending stresses and prevented heat expansion have not been considered in this work as these are subject to relaxation whose influence is not yet sufficiently well-known for district heating pipelines.

6.4 Thermal Loads (Ageing)

All plastics are subject to ageing when put under stress for a long time, particularly as a result of higher temperature and oxygen, because their thermal stability is limited. Should such materials be used at temperatures much higher than 20 °C, then information on the time of the beginning of the ageing process is essential. It must be tested whether a sharp decline in the creep curve can be determined or not by means of extrapolation for the temperature being considered here within the required minimum period of operation.

In the case of all plastics, ageing leads to a reduction in the molar mass, breaking stress, creep strength and then to brittleness and finally to cracking, which presents a risk for a reliable operation.

The life time curves for PEX and PB were determined in a statistically reliable calculation procedure based on [8]. They are presented in Fig. 6-2 as lines c and e.

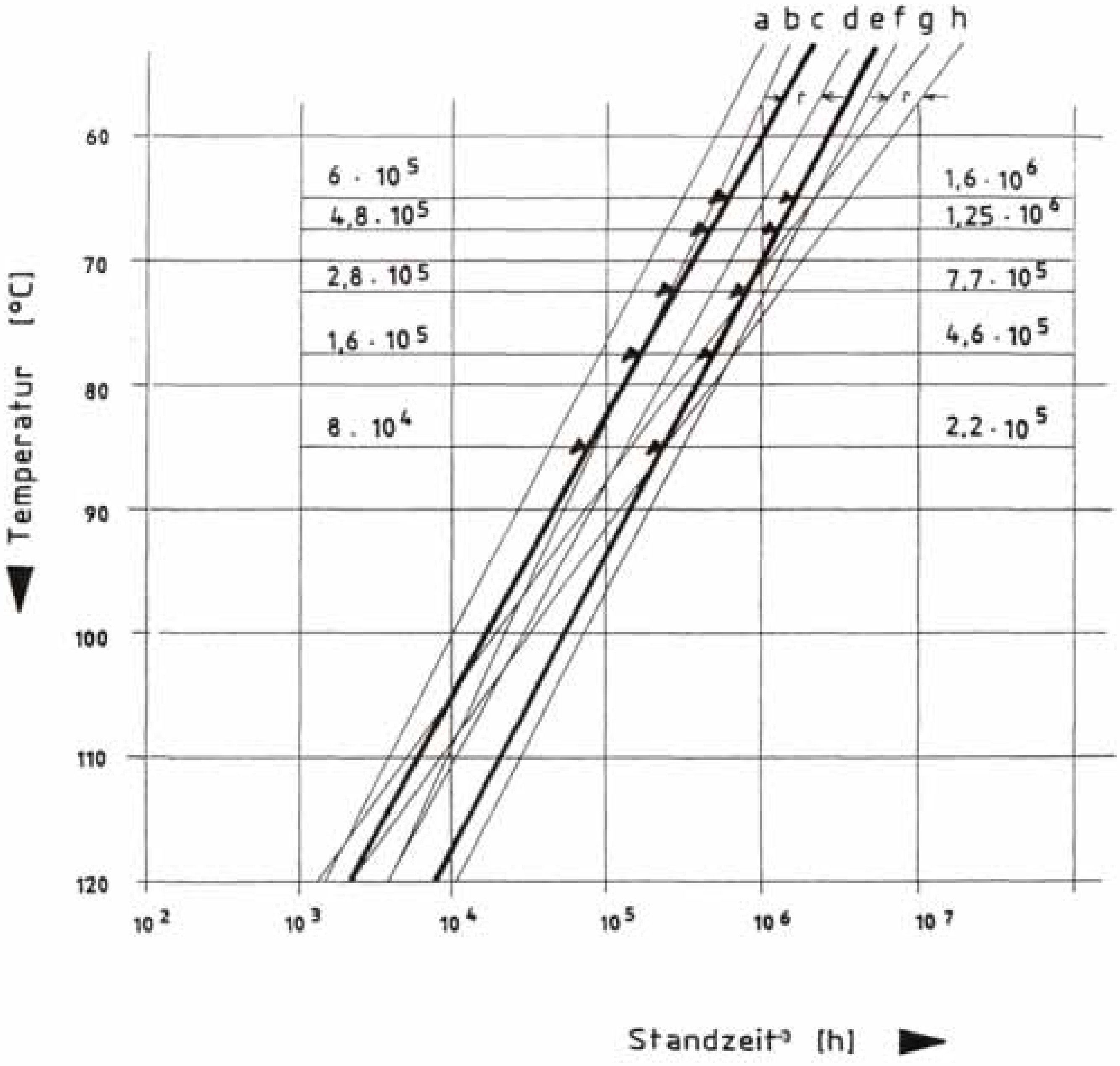


Fig. 6-2: Various Lifetime Curves for PE-X and PB

a) PE-X P1, average value (from [9])
b) PB, average value
c) PB, least value
d) PB, average value (from [6])
e) PE-X P3, least value
f) PE-X P3, average value (from [9], however, parallel to a)
g) PB, least value
h) PB, average value

For the assumed temperature range, they lead to creep times of

$T_{x,PE\text{-}X} = 1.3 \cdot 10^6\ h = \underline{148\ a}$ for VPE (PEX) and

$T_{x,PB} = 4.84 \cdot 10^5\ h = \underline{55\ a}$ for PB

Thus, there is sufficient reliability regarding ageing.

6.5 Mechanical and Thermal Loads (Static)

For stressed periods which occur before ageing starts, there is also a certain stress dependability of the service life. As already mentioned in section 5, the prescribed operational pressure of 5 bar leads to a tangential stress in the pipe of about 2.22 N/mm^2. With a safety factor of 1.8, one obtains a stress of 4 N/mm^2.

In the following section the service life which can be expected for changing temperatures and constant pressures will be determined. For this the creep curves are extrapolated beyond the start of ageing. This procedure is acceptable as ageing has already been considered in the last section.

Result:

Both for PEX as well as for PB there are service lifetimes which are far beyond the start of ageing.

6.6 Load Limits

For operational pressures of up to 5 bar and a safety factor of 1.8, the mechanical load from internal pressure has no influence on the lifetime. Considering ageing of the two materials investigated, the start of ageing is far beyond the technical period of utilization.

Creep curves, such as those based on DIN standards 16892 and 16968,which do not include the steep decline, are not suitable for estimating the expected service life. In Sweden, valuable results from internal pressure creep tests are available and these can be used to determine the lifetimes [6] and [9]. For system designs, however, the measured average values should not be used, but minimum curves have to be construted presenting the decisive lifetime curves.

In summarizing it must also be pointed out that considerably higher stresses than the assumed comparative stress of 4 N/mm^2 (i.e. operating pressure 5 bar and safety factor $s = 1.8$) cannot be borne in the case of a variable mode of operation up to 90 °C.

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