International Energy Agency

IEA District Heating and Cooling

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

Plastic Pipe Systems for DH, Handbook for Safe and Economic Application

Published by

Netherlands agency for energy and the environment

Novem

Acting as operating agent for the IEA District Heating and Cooling project

1999:T6

IEA R&D Programme on
District Heating & Cooling

Plastic Pipe Systems for DH, Handbook for Safe and Economic Application

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March 1999

International Energy Agency

The International Energy Agency is an autonomous body which was established within the framework of the Organisation for Economic Co-operation and Development (OECD) in November 1974. The IEA carries out a comprehensive programme of energy co-operation among its 24 member countries. The main goals are:

- to maintain and improve systems for coping with oil supply disruptions;
- to promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- to operate a permanent information system on the international oil market;
- to improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- to assist in the integration of environmental and energy policies.

Introduction

Energy efficiency results not only in a saving of fuels, but also in a consequent reduction of environmental pollution. In the range of means by which countries can improve their energy efficiency, District Heating is a major item. It is an externally flexible technology involving the increased use of indigenous or abundant fuels, the utilisation of waste energy and last but not least, combined heat and power production.

District Cooling is a rapidly growing technology with additional benefits for energy efficiency and the environment. New development involve the integration of cooling with combined heat and power, either with the central production of chilled water or by installing absorption chillers in customers' buildings using heat from the District Heating system. Thus, higher efficiencies and more even seasonal loading can be achieved in an environmentally friendly way.

The Implementing Agreement 'Programme of Research, Development and Demonstration on District Heating and Cooling' offers member countries of the International Energy Agency (IEA) a valuable opportunity for collaboration.

Programme aims

From 1983 to 1996 four working programmes, so called Annexes, were carried out. The main items of Annex I, II and III were:

- heatmeters
- cost-effective distribution systems;
- review of R&D projects;
- consumer installations;
- Advanced Transmission Fluids;
- demonstration of environmental benefits of District Heating;
- piping techniques, including plastic jacket pipes, CFC-free foams and plastic medium pipes for small diameters;
- District Energy Promotion Manual;
- development of dynamic simulation models of consumer heating systems.

Annex IV, which started in 1993, included the following items:

- development of a design guide for integrating District Cooling and Combined Heat and Power;
- Advanced Transmission Fluids: research on Friction Reducing Additives;
- piping technology: study on bendpipes and on connections to pipelines in operation, composition of manual on District Heating pipelines;
- development of supervision methods for District Heating networks;
- identification of the most efficient combination of substations and installations in District Heating systems;
- study on the effect of temperature variations in preinsulated District Heating pipes, low cycle fatigue;
- development of long-term co-operation with East European countries;
- international information exchange.

The results of the project activities have been published and disseminated in the participating countries.

Annex V.

In 1996 it was decided that the programme should be extended for a further three year period: *Annex* V. Participating countries in this Annex are: Canada, Denmark, Finland, Germany, Republic of Korea, the Netherlands, Norway, Sweden and United Kingdom. All these participants, except the Republic of Korea are IEA members countries. The Executive Committee decided upon the following items for the Annex V programme:

- Cost-effective District Heating networks
- Optimal operation, operational availability and maintenance in DH systems
- Optimisation of DH operating temperatures and appraisal of the benefits of low temperature DH
- District Heating and Cooling in future buildings
- Combined heating and cooling, balancing the production and demand in CHP
- Fatigue analysis of DH systems
- Handbook on plastic pipe systems for District Heating
- Further activities

More information

For more detailed information about this IEA programme. Please contact your country's representatives on the Executive Committee or Novem, the Operating Agent. Information is available on the Internet, http://www.iea-dhc.org

Plastic Pipe Systems for District Heating – Handbook for Safe and Economic Applications

Executive Summary

Introduction

Plastic medium pipes have in some countries, especially in Scandinavia, been used for many years in floor heating applications and in smaller local networks. In Denmark these pipes are also quite common for smaller district heating pipelines. In spite of years of experience, there still exist doubts about the possibilities of using plastic pipes in district heating applications, mostly because of the limitations in pressure and temperatures which must be observed when using plastic medium pipes. The use of plastic medium pipes is also limited to relatively small dimensions, i.e. below 100 mm diameter, which makes it necessary to mix steel pipes and plastic medium pipes in many applications, a combination for which experience so far was not systematically documented.

The aim of the project is to compile know-how and installation experience from various countries and to present the results about plastic medium pipe techniques in the shape of a handbook. The handbook describes the basic properties of plastic materials involved and the conditions for its applications, as well as recommended laying and installation techniques to be used for receiving both technically and economically favourable results.

The handbook is divided into two main parts: An ***engineering part A*** describing the main aspects of using and applying plastic medium pipes, including also economical system aspects, and a ***material part B***, giving more detailed background information about the specific material properties as an Appendix. Some ***field projects*** are documented in the Appendix part C.

A - Engineering aspects

The plastic medium pipe systems are described for all makes commercially available on the European market (i. e. in more than one country) for the last years. This implies that products under development or just pilot products are not included. This limits the make description to the following systems:

Bonded pipe systems with PEX:
ABB-PEX flex (ABB Isolrohr), Brugg-Calpex, Isoplus-Isopex, Lögstör LR-Pex, Tarco PEX/FLEX.

Non bonded pipe systems with PEX:
Uponor Ecoflex.

Pipe systems with other material than PEX
Flexalen.

A complete list of properties of these systems mentioned above is included in *Table 2.1*. It gets evident from this list, that the PEX medium pipe is the prevailing pipe material and that practically all PEX-pipes to be used for district heating have a diffusion barrier of EVOH (ethylenvinylalcohol) which reduces the risk of oxygen diffusion to a great extent. Polybuthylene (PB) - with or without a diffusion barrier - is only offered by one manufacturer. PEX pipes are available in dimensions up to DN 100 mm whereas the PB pipes are offered also up to DN 125 mm. For pipe joints, a variety of joint systems are available, most of them are of type press or screw fittings. An exception is the PB pipe, which can be welded.

The advantage of plastic medium pipe systems is their flexibility. This holds not only for the plastic pipe but also for the total pipe system including insulation and jacket. Even for the largest diameter the minimum radius of curvature is given to 1.5 m. In all pipe systems, except the Uponor-Ecoflex and Tarco, the insulation is made by PU-foam, covered with an outer jacket of PE. The Ecoflex system uses PEX foam insulation with a PE jacket, and Tarco uses a PU-foam with a jacket of an elastomere ethylenic butylacrylate.

The most important difference between plastic pipe systems and preinsulated steel pipes is their simple and quick assembly. Whereas a typical time for the construction of a section of preinsulated pipes might be counted in weeks, plastic medium pipe systems can be installed within a few days.

In assembly, only simple tasks have to be carried out which can be completed quickly. For this reason it has been shown that the same contractor can manage all installation work. The pipe ditch is kept quite narrow with a minimum of excavated material since no welding work has to be made down in the ditch (except some large holes for joints or service Tees). The sand bed can be immediately filled up, the plastic pipe laid down in its full length and the ditch can be refilled within hours except may-be the excavation of larger holes made for joints or branches. By that way, roads are usually only blocked for some hours, bridges are not required and traffic interruption and other impact to the public is kept at a minimum.

Connections of PEX-pipes are best carried out as press connections. They can be mounted using a special tool far more quickly than a welded connection on a steel pipe. Visual control of the joints is sufficient. However, PB pipes are commonly connected by welding.

Whereas the pipe laying effort for the main pipe system is considerably lower for plastic pipe systems compared to preinsulated pipes, branches require about the same effort for both systems. In plastic medium pipe systems, branches are produced very often with prefabricated Tees and the joints have to be carefully insulated and tightened.

Comparing plastic medium pipe systems with preinsulated steel pipes it can be stated that - all work considered - the effort spent for laying plastic medium pipe systems is very much less than for preinsulated steel pipes. This results also in lower total pipe system costs in comparison with the preinsulated pipes. In studies made in Sweden, Germany and Denmark it was shown that the total system costs are well below those for preinsulated pipes up to DN 65, the difference being larger the smaller the dimensions are. That means that the main advantage of plastic medium pipe systems can be found in applications where the transported energy is below 500 kW.

B - Material aspects

The most dominant questions concerning the plastic medium pipes are the limitations in temperature and pressure at one hand and the oxygen diffusion at the other hand.

These questions have been investigated in different laboratories in Europe as well in the USA. Plastic pipe properties have been improved during the years and early measurements should be taken with caution. Reliable measurements for the lifetime expectancy of PEX and PB are nowadays available. These measurements are based on both real time laboratory measurements for more than 10 years and accelerated measurements at elevated temperatures and show that the time to failure is depending on both pressure and temperature. By taking mean values of the time to failure over different measurement series, lifetime diagrams as function of temperature and pressure can be constructed. Such diagrams are now proposed to be included in the new standard for plastic pipes.

For a district heating application with a temperature dependent supply temperature (i.e. 90 °C winter and 70°C summer) and an operating pressure of 5-6 bars, the expected life time can be calculated to be >100 years for PEX and > 60 years for PB pipes.

An important question is that of oxygen permeation through the plastic pipes. Untreated PEX and PB material exhibit such a high rate of oxygen permeation that such pipes only can be used in special applications where all metallic materials in contact with the water must fulfil fresh water quality standards.

Therefore plastic pipes are covered with permeation barriers in order to reduce the oxygen permeation. For PEX as well as nowadays also for PB, all commercial makes for district heating use ethylenvenylalcohol, EVOH, as such a barrier.

Measurements of oxygen permeation through plastic pipes are very difficult to carry out and can easily be based by systematic errors. In recent times, such measurements have been performed on PEX pipes by laboratories in Sweden, Denmark and Germany. Usually such measurements are related to a given pipe dimension. Depending on the temperature and the test site, the permeation difference between systems with and without barriers is in the orders of 10 - 2000.

The most important question is which impact the remaining oxygen permeation has on the possibility of connecting plastic pipes to steel systems. Investigations have been performed at Fernwärmeverbund Saar in Germany. The expected corrosion impact from oxygen due to plastic pipes in two combined systems with twice as much plastic pipe volume as steel pipe volume, was calculated to be less than 0.03 - 0.1 mm loss of steel pipe thickness during 35 years. A study in Denmark resulted in still lower values. Hence from these and other measurements the conclusion can be drawn that the equilibrium contribution of plastic pipes to the oxygen leakage is negligible and plastic pipe systems can be mixed with steel pipe systems.

The influence of the diffusion of water vapour through the wall of PEX medium pipes on the pipe system is under investigation in Germany. In pipe systems consisting of media pipe, insulation and jacket, accumulation of moisture in the insulation of the pipe-system or also on the inner wall of the jacket can be expected, if the permeability of the jacket is less than that of the medium pipe. Moisture which accumulates in the insulation is expected to reduce the thermal resistance of the insulation. This on the other hand will increase the temperature of the jacket and hence increase its permeability until an equilibrium will be reached. Hence each pipe system is expected to have its own balance of humidity depending on operation temperature and materials involved in jacket and insulation. It is expected that the industry will use results of these measurements for further optimising the water diffusion properties of their plastic medium pipe systems.

C - Field demonstrations

Three examples from Sweden, Finland and Germany are presented in Appendix C. In these projects, care was taken of using the advantages of plastic pipes as system size. Pipe dimensions and operating conditions were concerned. In two of these projects, the advantages of constructing the smallest pipe lines by means of Twin or even Quadruple pipe systems has been used. Although it is difficult to compare the costs of built systems and non-built calculated systems, the general conclusion was that a total cost advantage for small pipe systems (< DN 65) exists compared to conventional steel pipe techniques.

However, it has been found in parallel projects in the same countries (Sweden, Germany, Finland), that new installation techniques such as cold-laying and refill techniques for steel pipe systems and also the use of flexible steel and copper pipes, especially at operating conditions comparable to those of plastic pipe systems, also lead to reduced system costs.

NOTA BENE:

Summaries of Conclusions and Recommendations will be found in chapter 7 for the engineering part and in chapter 10 for the material part.

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Section A

ENGINEERING ASPECTS

1 Introduction

Plastic medium pipes have in some countries, especially in Scandinavia, been used for many years in floor heating applications and in smaller local networks. In Denmark these pipes are also common in district heating systems. In spite of years of experience, many potential users still express concern about the feasibility of using plastic pipes in district heating, mostly because of the limitation in pressure and temperatures which must be observed when using plastic medium pipes. The use of plastic medium pipes is also limited by cost to relatively small dimensions, i.e. below 100 mm diameter, which makes it necessary to mix steel pipes and plastic medium pipes in many applications, a combination for which experience has not been systematically collected to date.

Plastic medium pipes have undergone appreciable development during the last two decades. Compared to earlier pipe systems, the range of maximum operational temperature has been increased and oxygen permeation barriers have been adopted. This holds especially for PEX which is the dominant medium pipe material on the market. Therefore many operators of district heating networks are now considering the advantages and possibilities which are offered by plastic medium pipe systems: Especially in the low diameter range, the costs of distribution networks can be substantially reduced and installation techniques simplified, provided that pressure and temperature conditions can be chosen according to the operating conditions for plastic medium pipes. For this reason the District Heating Associations in different countries, e.g.: Sweden, Denmark and Germany, are working with their own recommendations for the plastic medium pipe systems. Furthermore, under the umbrella of CEN Technical Committee 107, Working Group 10 is preparing the publication of standards for plastic medium pipes.

With all these activities under way it was the opinion of the Executive Committee of IEA-District Heating & Cooling Implementing Agreement that the time was mature for summarising the experience of plastic medium pipes for district heating and to give guidance to those engineers and technicians in the field having experience with heat distribution, but being less experienced in the matter of plastic medium pipes.

Hence the aim of the project was to compile know-how and installation experience from different countries and to present the results about plastic medium pipe techniques in the form of a handbook.

Most of the experience can today mainly be gathered from three countries:

In ***Denmark*** district heating has a tradition of choosing as simple solutions as possible and the lowest design temperatures are used. Hence, for a long time plastic medium pipes play an important role in all but the largest district heating networks. Denmark is also the country with most European manufacturers of plastic pipe systems. The Danish Technical Institute has significant experience in testing and evaluating plastic pipes.

In ***Sweden***, a special plastic pipe system has been developed during the eighties in connection with a special system application technique- the Grudis system - and Studsvik Polymer AB is one of the most respected institutions regarding life expectancy measurements of plastic medium pipes. Sweden has also an important manufacturer of plastic medium pipes. In 1996 the Swedish District Heating Association worked out recommendations for PEX pipe systems and started a series of demonstration projects.

Germany has recently completed a 7 year long R&D project devoted to the safe use of plastic medium pipes with a combination of both laboratory and field tests. The Utility Fernwärmeverbund Saar was the main contractor for the German project and responsible for the field tests. Laboratory tests have been performed by TÜV München and Staatliches Materialprüfungsamt Nordrhein-Westfalen. Some other measurements were also carried out by the Fernwärmeforschungsinstitut Hannover.

The authors of this handbook were involved in the development work in Sweden and Germany. However, the creation of the handbook was guided by an Experts Group which was very helpful by adding the experience from other countries: In this context we would like to acknowledge the contribution of all the other members of the Experts Group for substantial contributions regarding both district heating experience and content of the handbook. This group is in alphabetical order:

Canada: Rob Brandon, Natural Resources Canada, CANMET

Denmark: Steen Palle, Løgstør Rør A/S

Finland: Veli-Pekka Sirola, Finnish District Heating Association

Germany: Horst Steinmetz, Fernwärme-Verbund Saar GmbH

The Netherlands: Gert Boxem, Novem B.V.

Sweden: Ture Nordenswan, Swedish District Heating Association.

United Kingdom: Paul Woods, Merz Orchard

In order to set the context of the handbook some criteria were established on the content. The technical and experience status should be that of autumn 1998 and only pipe systems available commercially in more than one country should be included. The handbook does not deal with experimental systems and does not include materials which are under development except as appropriate remarks under the chapter "Further Developments". Hence, these constraints imply that most of the content deals with and is valid for PEX pipes, and that only a limited amount of information is devoted to polybuthylene (BP) pipes. Polypropylene (PP) pipe systems are not included at all in this handbook.

The handbook is devided into two main parts: An ***engineering part, Section A,*** that describes the main aspects of using and applying plastic medium pipes, including also system economics, and a ***material part, Section B,*** giving more detailed background information about the specific material properties. Complementary and reference information is included in ***Section C, Appendices.***

In the ***engineering part*** the plastic pipe systems defined as the medium pipe, insulation and protecting jacket are described as well as components and techniques for joints and laying practice. Furthermore operational conditions and system examples are presented. An important section deals with the economic development of plastic pipe systems in comparison with conventional steel pipe technology.

The ***material part*** describes basic properties of the plastic materials involved and the conditions and ranges for its applications. This section also includes corrosion risks and possible requirements for water treatment.

Finally, as ***Appendices***, system examples from different countries and references to literature and standards are included.

Nomenclature

Nominal diameter
The nominal diameter DN of plastic pipes refers mormally to their outer pipe diameter. However, in order to facilitate the comparison with steel pipes, in this paper, DN refers to the ***pipe inner diameter*** if not stated otherwise.

Preinsulated steel pipes
The expression "preinsulated pipes" always refers to preinsulated steel pipes according to EN 253.

Twin pipes
The expression "double pipes" or "twin pipes" are equally used for pipe systems with two medium pipes within the same insulated jacket pipe.

Acknowledgements

The authors wish to thank the following companies and experts for valuable information and contributions:
John Ljungqvist, Wirsbo Sverige, Sweden
Harri Siekkinnen, OY Uponor AB, Finland
The authors also wish to thank
Mr Rob Brandon, Natural Resourses Canada, Canmet, Canada, for important contribution with language checking and
Mrs Inga-Lill Furusten for an invaluable editorial effort.

The Figures 8.1 - 8.4 are published with permission from Wirsbo Bruks AB and are taken from their book "Water and Pipes" [20].

2 Plastic pipe systems

In the following chapters, plastic pipe systems presently available on the market will be introduced. The description is not intended to be a repeat of the text found in the manufacturers' catalogues, but is a report of all the systems from the same point of view so that their characteristic properties can be better compared. Only systems that are available internationally will be considered. Special developments which are still being tested in pilot plants or which are not yet being offered outside country borders have not been included.

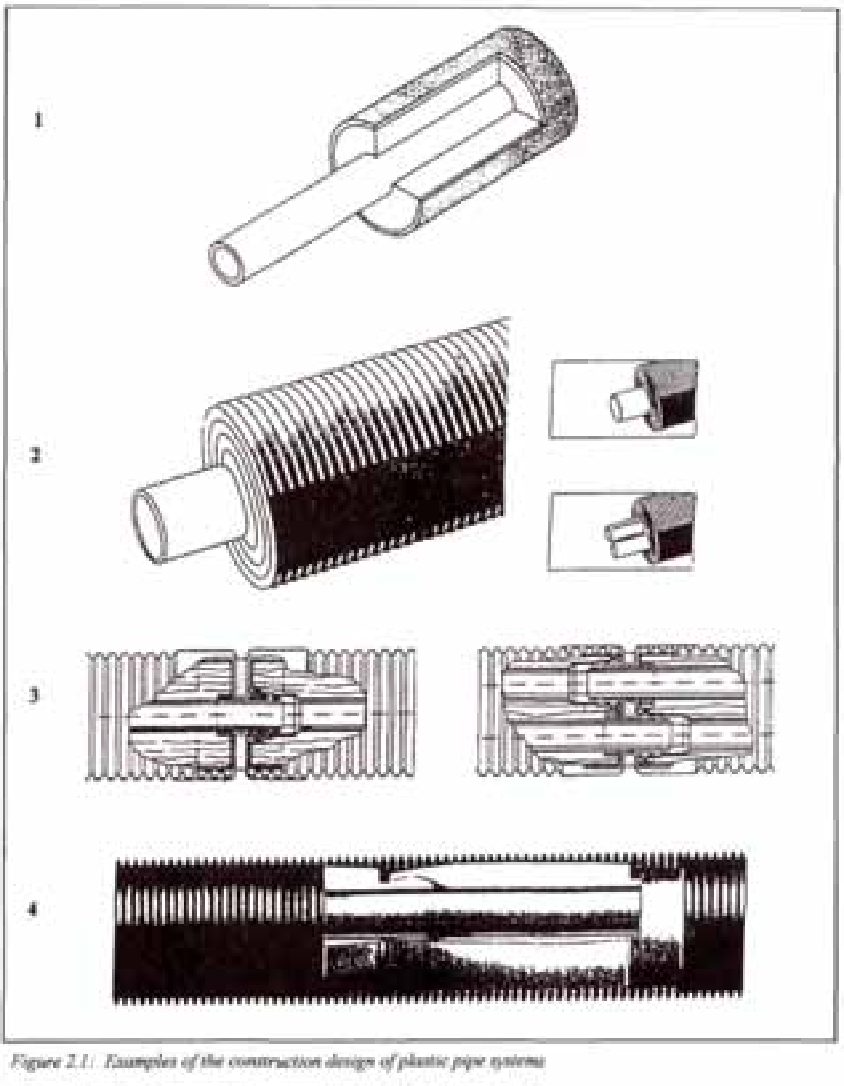


Figure 2.1: Examples of the construction design of plastic pipe systems

Type 1. Compound construction (systems Lögstör LR-PEX, Tarco-PEX)
Type 2. Design in layers without a join (System ECOFLEX)
Type 3. Pipe insulation elements for plastic medium (System Wirsbo /M-RO-PEX)
Type 4. System consisting of individual elements with PB-medium pipe (System Flexalen)

This is necessary because there is a large fluctuation in the supply of these pipe systems. In addition to products which have proved themselves over many years, new developments are always appearing and there are other changes in supply as a result of companies amalgamating and being reorganized. This industrial activities show that these new pipe systems have favourable prospects of development.

2.1 Description of plastic pipe systems

All plastic pipe systems are characterized by having the water medium pipe made of plastic. They are covered by insulation, usually of polyurethane foam, but in some cases of PEX-foam or mineral wool. The outer cover is formed by a jacket pipe once more of plastic.

In spite of this similar principle of construction for all systems, the details and their functional operation are very different between different systems. The differences consists of:

- Material of the medium pipe, e.g. PEX or PB
- Pipe arrangement: Single or double (twin) pipes
- Material for the thermal insulation: PUR or PEX-foam or mineral wool
- Design of the jacket pipe: Smooth, corrugated
- Construction: fixed or loose connection between the medium and jacket pipe
- Joining technique: PEX medium pipes joined by fittings
- Physical dimensions including unit lengths.

Figure 2.1 gives an impression of the variety of the systems. For this reason, plastic pipe systems cannot be assessed uniformly such as preinsulated steel pipes according to CEN 253. Pipes of the type 1 are found most frequently on the market.

The plastic medium pipe imposes a limit on the highest temperature and operating pressure allowed. Although there are differences from one manufacturer to another, the general limits of safe operations are about:

Temperature: intermittent up to 90 - 95°C
constant 80 - 90°C

Pressure: 0.6 MPa (for individual very small pipelines 1MPa).

As plastics are not absolutely gas-tight, there is a concern that oxygen which gets into the district heating water from the outside can result in corrosion of steel components in the system. Plastic pipes for district heating networks now include a barrier layer to prevent oxygen permeating, see Section 9. Pipe material without an oxygen diffusion barrier is considered to be unsuitable for use in district heating networks and hence will not be treated here.

Generally, thin polymer layers or metal foils are available as diffusion barriers in plastic pipes. In pipes for district heating networks, polymer films are used almost exclusively, and metal foil only in individual cases. There are some manufacturers who fit their pipes with a thick metal foil and the foil is thus also used for the pressure containing function. These pipes are then virtually metal pipes, protected from corrosion by plastic layers. Such pipes will also not be dealt with here, as, from a cost point of view, they are not competitive with pipes with a polymer barrier layer and cannot be used even in the near future in district heating applications.

Only complete pipe systems will be presented where, in addition to the pipe material, all components such as connections, formed pieces, transition pieces, and even the necessary tools and technical support are available from the supplier. It should be possible to construct the pipeline with the available parts without additional delivery from third parties being necessary.

Of the 4 pipe constructions, presented in Figure 2.1, the systems 1 and 2 are most often found in current installations whereas systems 3 and 4 are not as frequent or are preferred in particular countries. System 1 is most similar to the well-established preinsulated steel pipes. Apart from having a plastic pipe instead of the steel pipe, the respective products also show considerable differences regarding details.

The most important functional units of all these pipe systems are:

- Medium pipe
- Thermal insulation
- Jacket pipe
- Pipe joints.

In the following, these components will first be described in more detail and the design variants discussed regardless of the product. In Chapter 2.2 the individual products will be dealt with in detail, as they are found on the market today.

It has already been mentioned that the manufacturers follow different marketing strategies. A few of them only offer plastic pipe systems for very small diameters. Thus they assume that plastic pipelines are laid in combination with preinsulated pipes. The network then consists of lines of preinsulated pipes and house connections of plastic systems.

Other manufacturers deliver plastic pipe systems up to DN 110, so that small CHP-networks or secondary networks are completely equipped with plastic systems. Only one manufacturer (Flexalen, Austria) offers plastic systems above DN 100 and plans to extend this range still further.

2.1.1 Medium Pipe

In today's pipe systems, the medium plastic pipe consists either of cross-linked polyethylene (PEX) or of polybutylen (PB). Mostly PEX-pipes have been installed whereas one supplier uses material PB. PEX-pipe is today a mass-produced article, because it is manufactured in great quantities for floor-heating systems, whereas PB is installed to a much lesser extent. The main difference between the two materials is that PB can be welded whereas PEX must be installed with metal connecting elements. However, PB is a plastic material, which is not very easy to work with.

The pipe material is manufactured in an endless process and rolled onto drums, large PB-pipes are also produced in fixed lengths. The basic pipe is normally produced in mass-production as a semi-finished article and supplied to a pipe system supplier for further treatment. The system supplier fits the pipe with thermal insulation and the jacket pipe and completes it with the necessary attachments. Many system suppliers use the same basic medium pipe, which is a standard product. For reasons of competition, the brand name of the basic pipe is sometimes changed.

Most plastics show certain permeability to gases. For district heating operation there are two important diffusion processes. See Figure 2.2: First, small quantities of oxygen permeate from the air through the jacket pipe, insulation and PEX pipe and dissolve in the hot water. This oxygen is a danger to steel components such as radiators and boilers in the heating circuit. They can corrode if sufficient quantities of oxygen are available.

Secondly, water vapour moves through the plastic pipe wall to the outside. If it cannot escape through the jacket pipe it accumulates in the thermal insulation and increases the thermal conductivity of the insulating material. Within the lifetime of a district-heating pipe, heat losses should not become so high that the function of the pipeline or its economic operation is endangered.

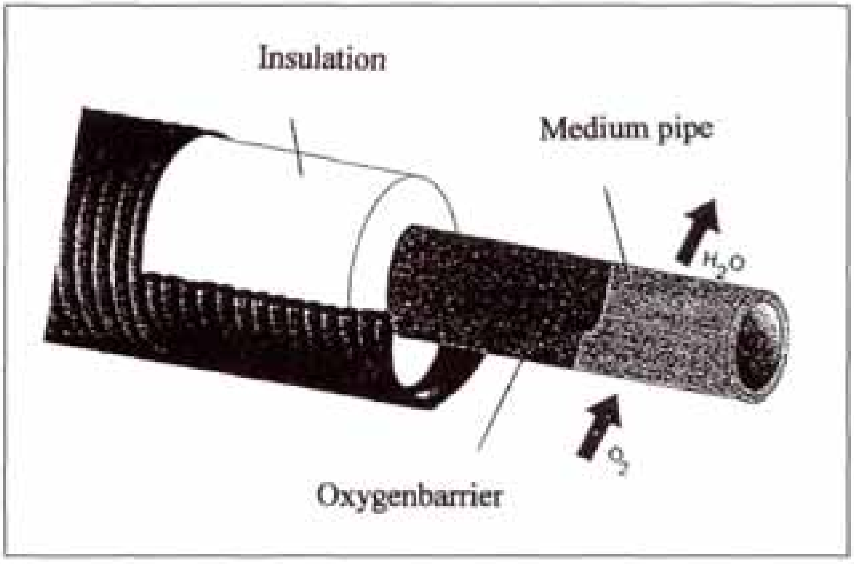


Figure 2.2: Diffusion through a PEX-pipe.

The diffusion of oxygen through the pipe is prevented by a barrier layer consisting of a thin film of a plastic having an extremely low permeability for oxygen. A thin layer of the material EVOH, ethylenevinylalcohol, reduces the permeability by a factor of about 1000 and is then so low that it can be tolerated by a district heating network. Users have expressed

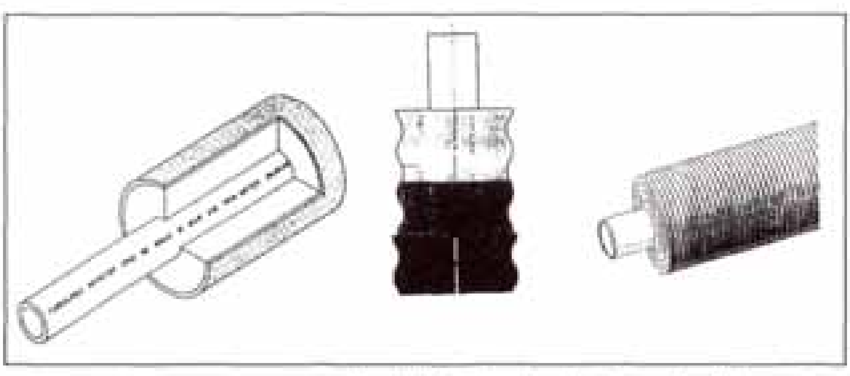


Figure 2.3: Design of culvert pipes – smooth and corrugated surfaces.

the wish that the barrier layer should be colored so that damage can be easily recognized. Although manufacturers of PEX-medium pipes say that coloring is a simple process, only one brand of pipe is colored at present.

The diffusion flow of water vapour is from the inside to the outside corresponding to the partial-pressure gradient. The EVOH-barrier for oxygen is ineffective for water vapour. The water vapour leaking through the medium pipe must be able to flow out of the jacket pipe so that the functionality of the pipeline is maintained, see Chapter 2.1.3 Jacket Pipe.

It is well known that metals are gas tight and that diffusion does not occur. Medium pipes with a diffusion barrier of metal foil offer good protection both against oxygen diffusion as well as water vapour diffusion. However, metal foils with their physical properties that are different from plastics disturb the structure of the pipe wall. For instance, the different thermal expansion coefficients can lead to a separation between the metal and plastic layers and therefore to a weakening of the pipe construction and its barrier function. Also the application of pipe joints can be problematic with this type of pipes.

2.1.2 Insulation

The following materials are used as thermal insulation:

- PUR-foam as composite foam
- PEX-foam
- Mineral wool
- PUR-molded insulation

PUR-foam is the most favoured material for thermal insulation. It has proved to be highly suitable for district heating networks, it has excellent thermal insulating properties and is particularly good for continuous production of plastic pipe systems. The foam used here is often softer than in the case for preinsulated steel pipes. This is possible since it is not so thermally and mechanically stressed. The softer foam gives the pipe more flexibility so that it is easier to handle at the building site.

When the compound pipes are foamed, the space between the medium and jacket pipe is completely filled so that water cannot creep along the pipe if a leak should occur. Foams also have a very high permeability to gases compared to solid materials.

A frequently used product, see Chapter 2.2.2.1, uses PEX-foam as insulation. Strips of foam material are laid around the medium pipe; finally the layers are lagged.

Two specific pipe constructions are presented in Figure 2.1 No. 3 and 4. Pipe No. 3 uses mineral wool, with which the spaces of the pipe insulation elements are filled. Pipe No. 4 has a very special construction of the thermal insulation. The thermal insulation consists of spherical-molded parts, which can be fitted to form a tube. Each insulating body consists of PUR-foam, which is coated with a PP-shell. As the connection between two insulating bodies are formed as a ball and socket joint, this insulating tube can be very easily bent. However, this thermal insulation results in air filled cavities.

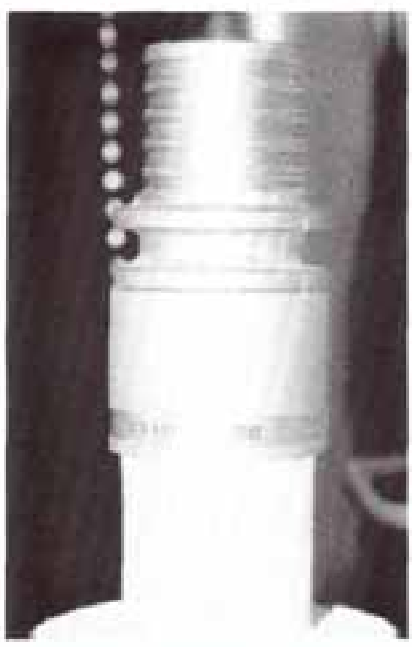


Figure 2.4: Press fittings for DH pipelines - series of the diameter range DN 16 to DN 80; different makes.

2.1.3 Jacket pipe

The jacket pipe separates the thermal insulation from the ground. The jacket must be capable of bearing a load, so that it can take up the foundation stresses of the ground, and the walls must be sufficiently thick so that they are not damaged during work at the building site.

Jacket pipes for plastic pipe systems have 3 typical wall profiles, see Figure 2.3. Normally, jacket pipes are smooth. The thickness of the walls is thinner in most cases compared with preinsulated pipes. Other pipe systems use slightly or even strongly corrugated jacket pipes. The wave contour helps the flexibility of the pipe and can also improve the pipe's load bearing capability.

Usually low-density polyethylene (LD-PE) is used as material for jacket pipes. LD-PE has a higher permeability for water vapour, so that compared to HD-PE these jacket pipes favour the diffusion of water vapour from the system into the ground, see also Section 8.5. However, LD-PE has lower mechanical strenght than HD-PE.

As an alternative to the standard HD-PE jacket pipes, one manufacturer (Tarco, DK) offers the material ethylenic-butylacrylate EBA for the jacket pipe and has patented this system, European patent No. 0538538. This material is more permeable for water vapour than LD-PE. Since it is also more elastic than the PE-types, according to the manufacturer this pipe system is more flexible.

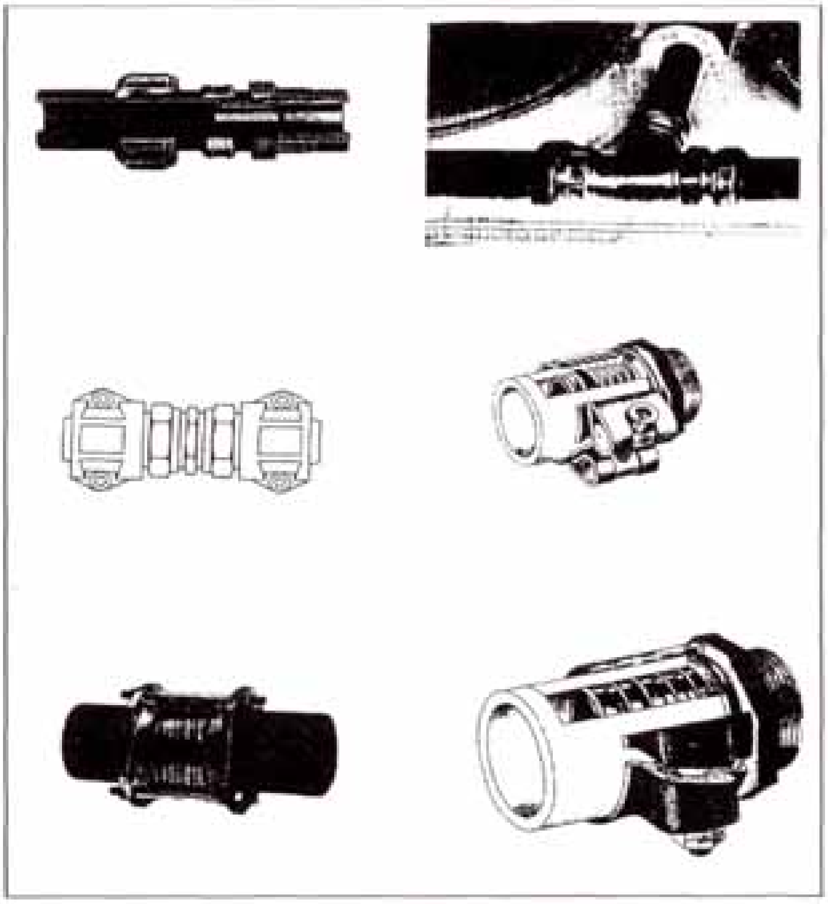


Figure 2.5: Different screw connections for plastic medium pipes.

2.1.4 Couplings and joints

Pipes of PEX cannot be welded and are therefore joined with metal coupling elements. Metal connections are offered in large numbers, not only for the different system product range. Usually there are several connector designs for each pipe diameter for each brand of pipe. However, not all connecting systems are suitable for use at district heating building sites. In particular, joints, consisting of many components and requiring special efforts for assembly, seem to be unsuitable for use in pipe trenches.

The most suitable connecting elements for district heating building sites are press fittings. They consist of metal rings with a thread, which connects the pipes once and for all by pressing them together with a special tool. Auxiliary aids are not necessary and the correct assembly can simply be checked visually. The press fittings are available for the whole diameter range of district heating systems. There are several product names for this system, for examples see Figure 2.4.

Pipes of polybutylene can be welded and joined using proven welding techniques. For details, see Chapter 2.3, the Flexalen system.

Besides press fittings there are a large number of other joints, which produce the tightness with the help of clamping nuts, clamping rings, clamping curves, pressure flanges etc. Often these are only used for a limited range of diameter. Several of these connecting systems were developed for water installations and can now be used for district heating networks as well. Many systems were also developed by manufacturers of medium pipes and are therefore being offered in a similar design for several different pipe systems. A selection of the different screw connections for PEX-pipes is shown in Figure 2.5.

The trend in the application is clearly going away from screw to press fittings. At this time almost all manufacturers offer press fittings for their systems. At first press fittings were only available for small pipelines, but today there are also some for plastic pipes of DN 80.

Since for several different systems, pipes are classified according to the same size standards DIN 16892/3, it is possible in principle to use press fittings from one manufacturer on another system. This can be useful in repair work. However, when building new pipelines, it is important to use only original components belonging to the system so that the warranty conditions of the manufacturer can be upheld.

2.1.5 Particular aspects of pipe connections to buildings

In addition to pipe material, manufacturers also supply the tools required and usually the pipe accessories as well. In the first instance these consist of the fittings or a building set, with which the transition from district heating network to the house system can be produced reliably and economically, see Figure 2.6. The building set consists of a foundation, which also serves as anchorage for the end of the plastic pipeline. In addition, it includes both shut-off valves for the outgoing and return pipes and provides a standard connection to the house system.

Retrofitted connections on existing pipelines are produced using branch shaped pieces, whereby the main pipeline is cut and a branch element fitted. This can either be a construction of screwed half shells, see Figure 2.12, for example, or it can be a compound component

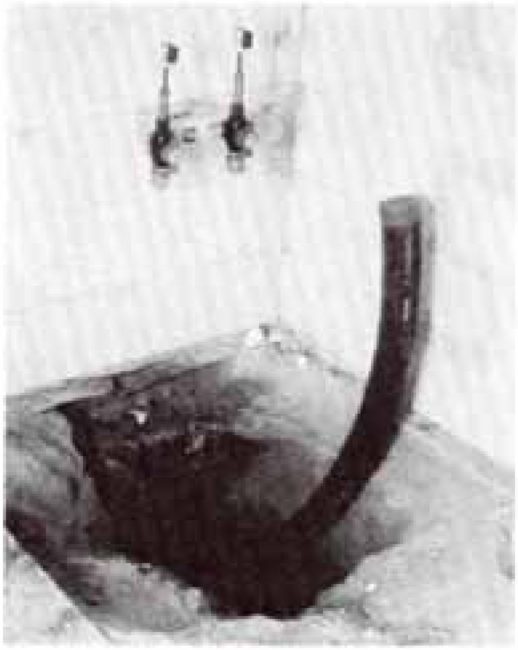


Figure 2.6: Assembly of house connecting fittings - joints prepared for the leakage test.

of medium and jacket pipe that is fitted into the pipe system with 3 sleeve joints. It looks like a shaped piece for plastic jacket pipes whereby the medium pipe of steel is equipped with press fittings.

For cost reasons, the number of fittings used in plastic pipelines is kept as low as possible. In addition to the small valves already described above for attaching the pipe to the buildings, shut-off valves for complete pipe sections are included in individual cases. These are

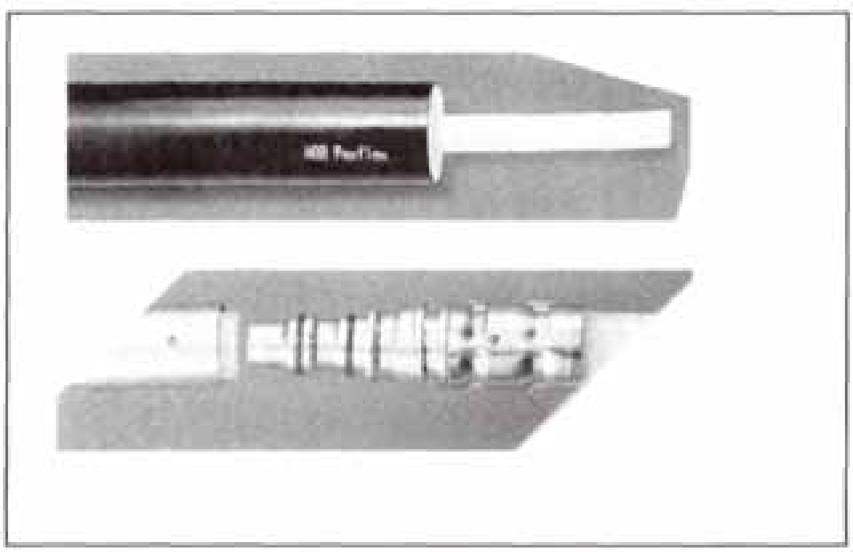


Figure 2.7: ABB-PEX flex system - bonded pipe joint of medium pipe.

preinsulated steel valves, as used for pre-insulated steel pipelines. For PB systems, small valves are available which can be welded into the PB pipes.

2.2 Systems with PEX-medium pipes

For the selection of pipe systems see introduction to Chapter 2.

2.2.1 Bonded pipe systems

2.2.1.1 ABB-PEX flex (ABB Isolrohr).

Basically the ABB-PEX flex-system has the same construction as a preinsulated pipe based on EN 253. The medium pipe is a plastic pipe of PEX with a diffusion barrier of EVOH. The thermal insulation consists of PUR-foam and forms the connection between medium and jacket pipe. The jacket pipe is made from PE-LD. Figure 2.7 shows the medium pipe and a connecting element.

Only 3 pipe diameters can be supplied for this system and these are DN 16, DN 20 and DN 25, whereby each nominal diameter is available in 2 wall thicknesses. The pipe comes to the building site as a single pipe system in a roll, and delivery length is from 20 to 200 m depending on the diameter.

The maximum safe loads are 80°C constant temperature, and the pipe material DN 16 and DN 20 can bear up to 1 MPa and DN 25 and the largest only 0.6 MPa. This pipe design is based on a minimum lifetime of 30 years.

The connecting elements of the medium pipe-line are metal connectors with sealing rings. They are pressed on with a special tool and cannot be undone. The tools and a completed connection are shown in Figure 2.8. In addition, screw fittings are available but only recommended when there is insufficient space to carry out press connections, for instance in connection with tee-connections.

All necessary shaped parts are available for making branches in preinsulated steel pipes or plastic pipelines. Jacket pipes are joined with metal half shells, which are foamed with PUR-foam for thermal insulation. Figure 2.9 shows examples of branch lines. The pipes must be kept to a minimum radius of curvature in the laying process. These are from 0.5 to 0.8 m. Minimum cover of about 40 to 50 cm is recommended.

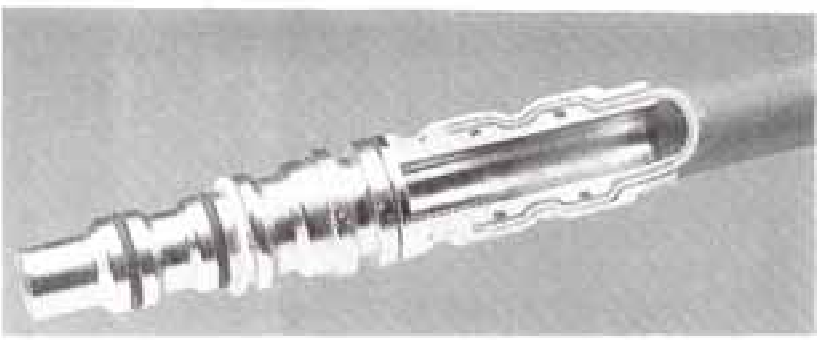


Figure 2.8: Tools for press fittings and joint with O-rings.

Figure 2.9: T-branches for main-line, 2 examples.

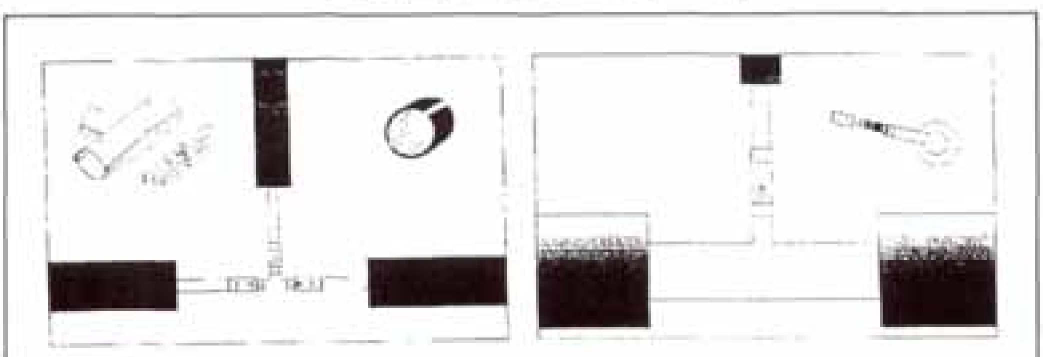
2.2.1.2 Brugg-Calpex

The Calpex district heating pipeline is a compound pipe based on a standard medium pipe of PEX. The medium pipe is fitted with an EVOH-diffusion barrier against oxygen. The PEX-pipe is surrounded by thermal insulation of PUR-foam, which is flexible. The jacket pipe is slightly corrugated. The light corrugation increases the flexibility of the pipe. The system is supplied as a single or multiple pipe system. Figure 2.10 shows the construction of the Calpex pipe.

Plastic pipelines are supplied as single pipelines for nominal diameters from DN 20 to DN 80 (110 x 10); double (twin) pipelines are provided in the range from DN 20 to DN 40. Large lengths of pipe material are either on drums or in rings. Material on drums is available in lengths of max. 830 m (DN 25) and greater nominal diameters are supplied in lengths up to ca. 200 m. The length supplied depends on the nominal diameter and the wall thickness. Most pipes are available in 2 wall thicknesses. Rings are supplied in shorter lengths.

The manufacturer gives the maximum safe loads for temperature and pressure for Calpex pipes as 95°C (variable operation) and 0.6 MPa respectively. As connecting systems both press fittings (Rehau system) and screw fittings (Beulco system) are available, see Figure 2.11. The transition to steel components is also possible with metal connectors.

Construction kits consisting of half shells of fiberglass reinforced plastic are available for branches, Figure 2.11. These shells are filled with PUR-foam. Shaped parts for the transition from single to double pipe systems are also supplied. These transition elements can be supplied with medium pipes of plastic or steel. Curved pieces are also available, see Figure 2.12.



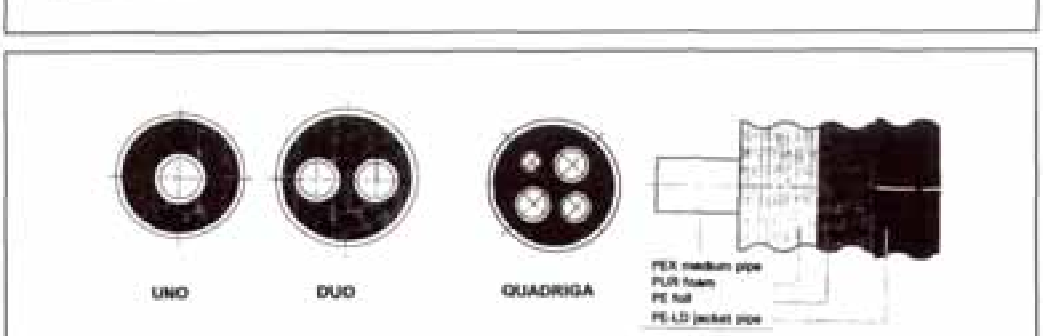


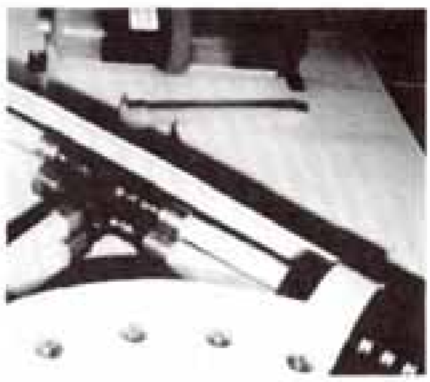
Figure 2.10: Construction Calpex district heating pipes.

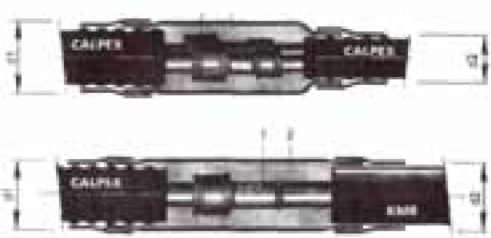
2.2.1.3 Isoplus-isopex

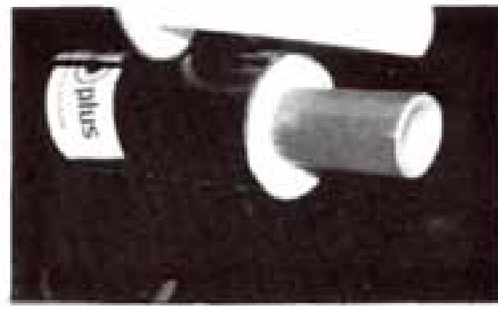
The medium pipe of the isopex system consists of a standard PEX-pipe. The EVOH-diffusion layer is coloured red so that damage to the barrier is easy to spot. Thermal insulation of PUR-hard foam satisfies the same specifications EN 253 as for preinsulated steel pipes. Similarly, the jacket pipe is manufactured according to EN 253, i.e. from the material PE-HD and of the same wall thickness as for preinsulated pipes. Figure 2.13 shows the isopex pipe with red diffusion layer and a connecting element.

Plastic pipes are supplied in

Figure 2.11







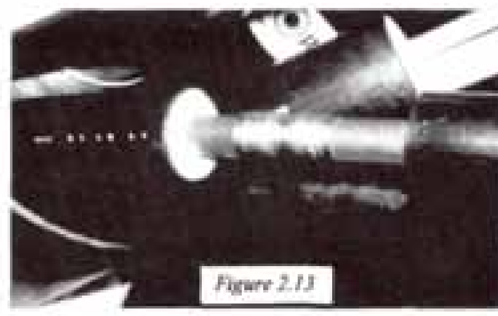


Figure 2.13

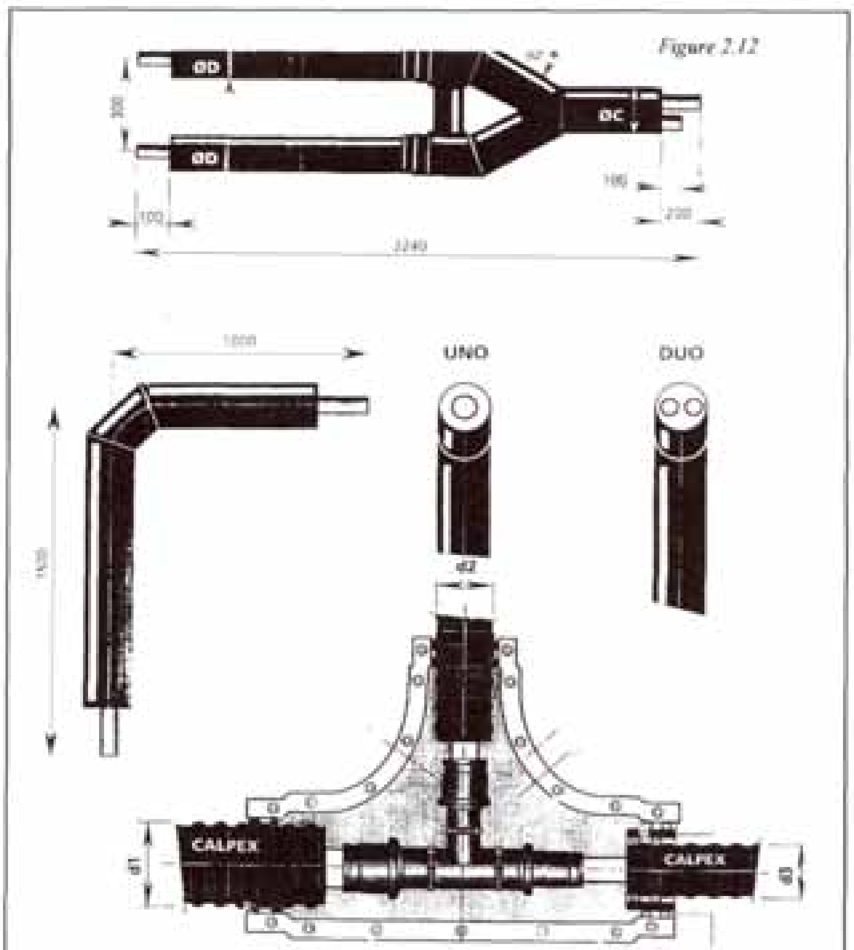


Figure 2.12

Figure 2.11: Press and screw fittings. Brugg-Calpex

Figure 2.12: Shaped pieces for the Brugg-Calpex system.

Figure 2.13: Isopex-pipe and joint.

nominal diameters DN 16 to DN 80 (100) as single pipes and, in addition, as twin pipes in the range DN 16 to DN 50. According to the manufacturer, the maximum length of pipe that can be supplied is the same for single and twin pipes and amounts to 360 to 50 m, depending on the nominal diameter.

The limiting safe loads for the isopex-system are a temperature of 95°C (variable operation) and a pressure of 0.6 MPa.

Press fittings are used for connections, see Figure 2.14. Screw connections should only be used in exceptional circumstances, as these are primarily intended for water line installations. The change-over from plastic to metal pipes is also possible with metal connectors.

Figure 2.14 shows 3 examples of ways of constructing branches in preinsulated steel pipes or PEX pipelines. For connections to preinsulated pipes, shaped parts or assembly branches can be used. Assembly branches are also applied when the branch is made to a pipeline already in operation by means of a pipe drilling process.

During the laying procedure the pipe is not allowed to be bent more than to a radius of 0.8 to 1.4 m. This varies according to the diameter and is valid both for single and twin pipes. The manufacturer recommends a minimum cover of 40 cm above the pipe vertex.

An assembled press fitting for the isopex-medium pipe has already been shown in Figure 2.13. The assembly is given in Figure 2.15.

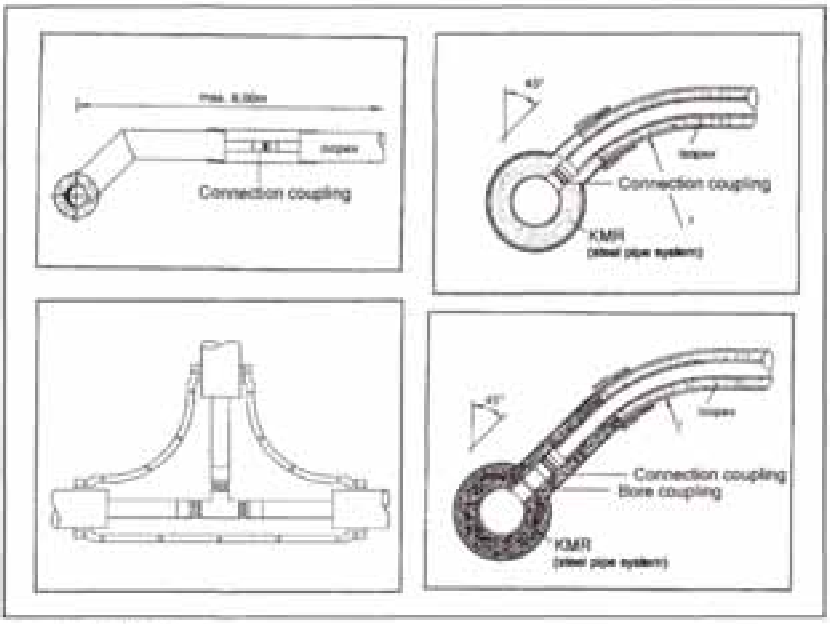


Figure 2.14: Branch constructions for the Isopex system.

Figure 2.15: Assembly of Isopex press fittings.

Figure 2.16: Construction of the district heating pipe LR-PEX.

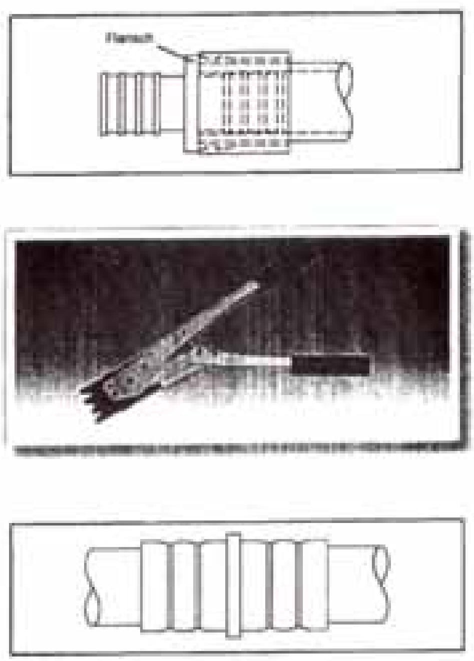


Figure 2.15

2.2.1.4 *Lögstör LR-Pex*

The Lögstör LR-PEX system is a compound system, which has the same construction as a plastic compound jacket pipe. The medium pipe is a plastic pipe of crosslinked polyethylene PEX, which includes a diffusion layer of EVAL (Wirsbo product) on the outside. The thermal insulation consists of PUR, which is medium-hard to improve the flexibility. The jacket pipe is a smooth pipe of polyethylene of low density

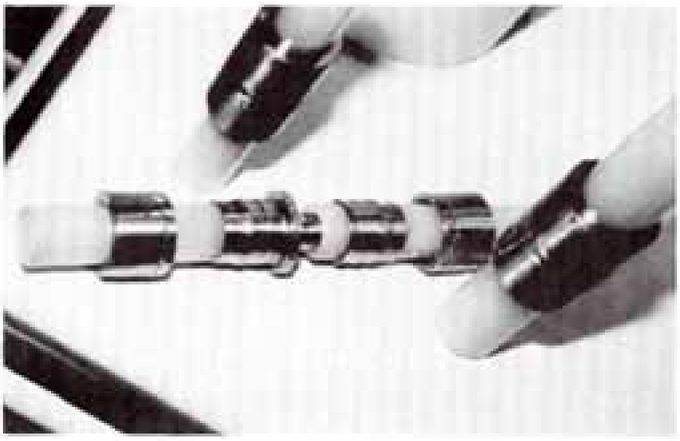
PE-LD. Figure 2.16 shows the construction of the pipe system.

Plastic pipes for nominal diameters of DN 16 to DN 80 (100) are offered. Pipes up to DN 65 are supplied in rolls, whereby the lengths are from 200 to 100 m. DN 50 and larger nominal diameters are available as pipe units, 12 m long, because of their stiffness.

The manufacturer gives the safe load limits as 95°C and 0.6 MPa. The two smallest nominal diameters DN 16 and DN 20 are strengthened and can tolerate PN 10 at 95°C. A flow speed of 2 m/s should not be exceeded to avoid erosion of the connecting elements.

The connecting elements for the pipeline are metal couplings, which can be used at places which are not easily accessable. There are 4 different types, whereby those shown in Figure 2.17 appear to be particularly suitable. In the top photo the individual parts of the press coupling can be seen. The relevant tool is shown in the lower picture. Suitable screw fittings for this system have already been shown in Figure 2.5. Using the metal connectors, a transition from plastic to metal is possible as required. For example, in the case of connections to the main pipeline and to branch lines.

Shaped pieces, which are built into the main pipeline, or combinations of connecting elements with screw fittings and mounting branches are available to construct branches.



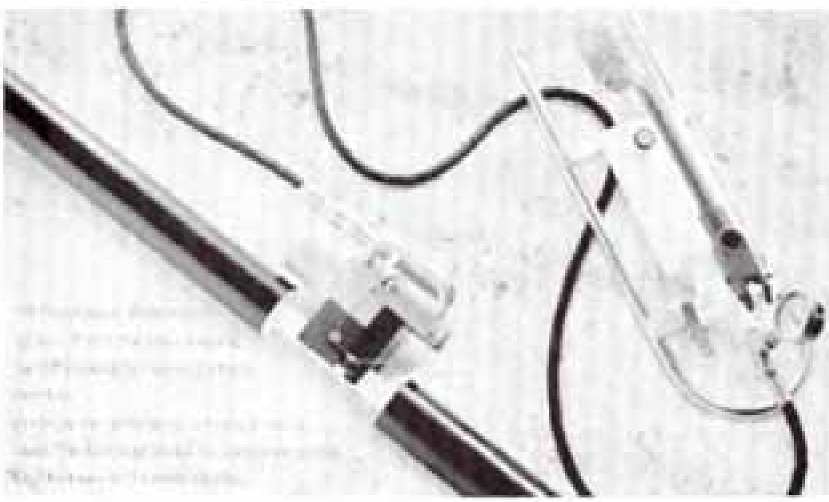
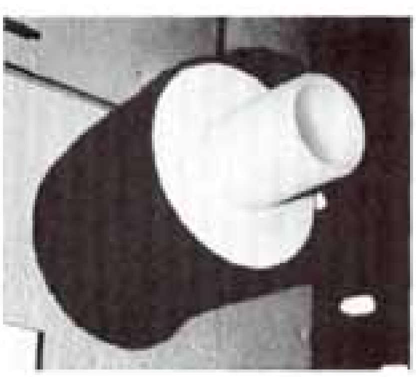


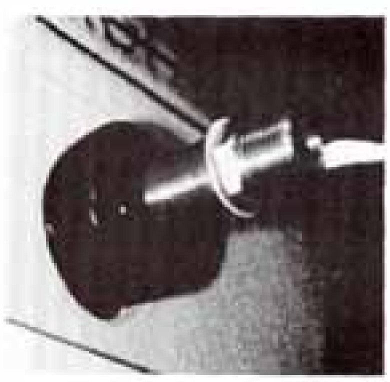
Figure 2.17: Press fittings for the system LR-Pex with tool

The connection of the jacket pipes is made with shrink sleeves, while thermal insulation is provided by using PUR half shells.

During the laying process, a minimum radius of curvature must be observed. For the nominal diameters DN 16 and DN 20 this is at least 1 m and for larger DN it is 1.5 m. The minimum cover is 40 cm.

Figure 2.18: Tarco PEX/FLEX system.





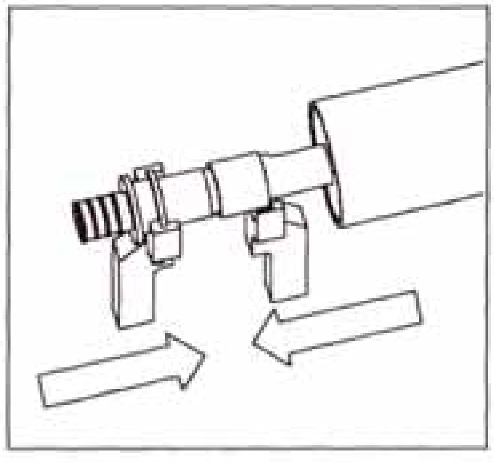


Figure 2.19: Tarco PEX/FLEX press fitting with tool

2.2.1.5 Tarco PEX/FLEX

The PEX/FLEX-system of the Tarco company is also a compound jacket pipe system. The medium pipe is a crosslinked polyethylene pipe with an oxygen diffusion layer of EVOH. The polyurethane foam is more flexible than that used in preinsulated steel pipes. The jacket pipe is made from PE-LD but on demand an EBA co-polymer (ethylenic butylacrylate) can also be supplied. Figure 2.18 shows a pipe end of the PEX/ FLEX system with and without a connecting element.

The PEX/FLEX system is available for nominal diameters from DN 16 to DN 40. The pipe is rolled up in lengths of up to 200 m, with nominal diameter DN 40 t. The maximum length is 45 m.

The manufacturer gives a maximum operating temperature of 95°C for variable operation. There are two series of pipe materials that can be delivered, the maximum operating pressure for one series is 1 MPa, and for the other one 0.6 MPa. The coupling elements for the medium pipe are made of metal. At first the medium pipe is expanded and then the press fittings are pressed together using a special tool. The press connector is also available as a transition piece with welding nipple on one side or screw connection. Figure 2.19 shows the pressing tool.

Branches for pipelines are constructed with metal fittings, to which press fittings are welded at the building site, see Figure 2.20. The jacket pipes are equipped with tees for assembly. Thermal insulation for the tees consists of PUR foamed on site at tees.

Figure 2.20: Assembly of the PEX/FLEX system

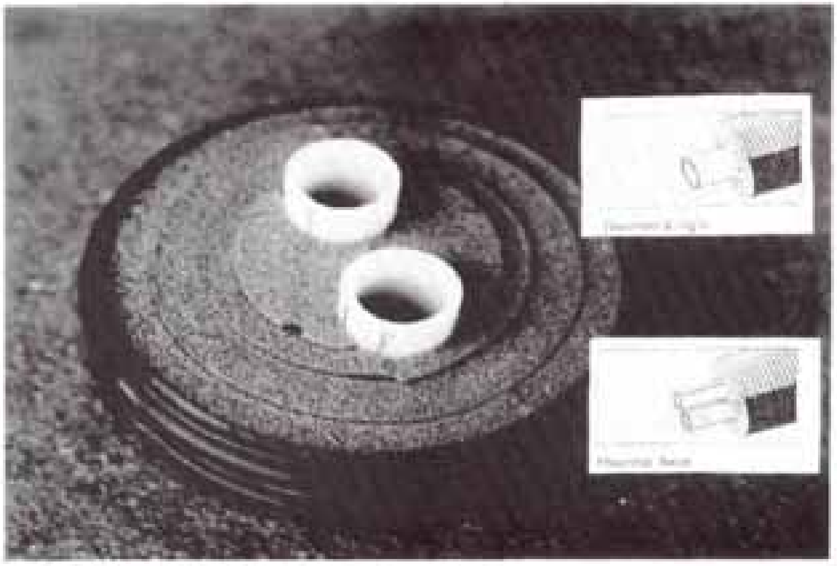


Figure 2.21: Construction of the Uponor Ecoflex systems.

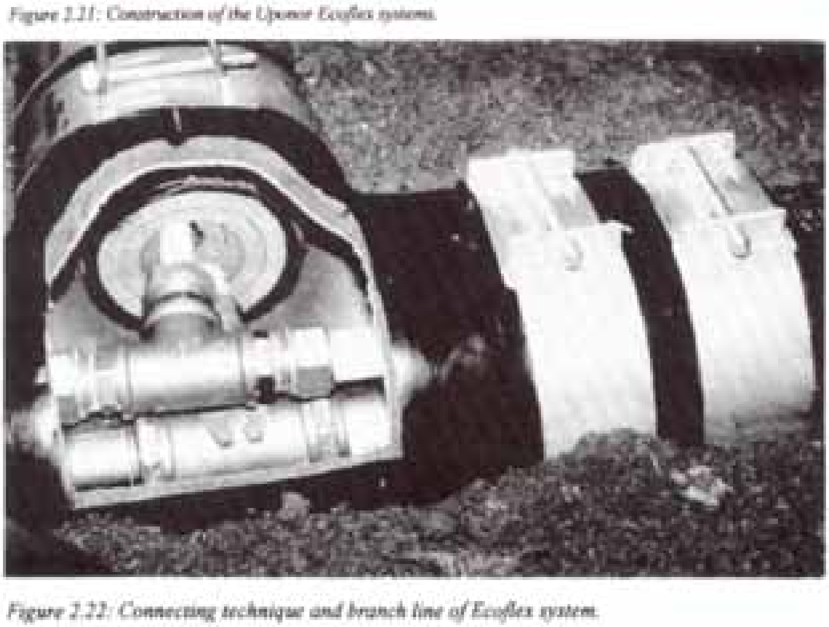


Figure 2.22: Connecting technique and branch line of Ecoflex system.

The smallest allowable radius of curvature for the PEX/FLEX pipe is only 0.4 m for DN 16 and 0.8 m for DN 40. The minimum cover over the pipe is 0.4 m.

2.2.2 *Non-bonded pipe systems*

In addition to compound construction, plastic pipelines of PEX are sometimes also produced as pipe systems with unbounded insulation. Two products having a PEX medium pipe are known and these are the Aquawarm and Ecoflex system. A few applications of the Aquawarm pipe are known from Sweden. Outside Sweden this system can be ordered but is very rarely applied. For this reason the system is only mentioned here for the sake of completeness. On the other hand, the Ecoflex-system is produced and installed outside Finland.

2.2.2.1 Uponor Ecoflex

The Ecoflex-Thermo-System for district heating pipelines is made of several layers. The medium pipe (Wirsbo product) consists of PEX and bears an oxygen diffusion barrier of EVOH. Thermal insulation is composed of several layers of foam mats, see Figure 2.21. The insulation material consists of crosslinked PE-foam. When a pipe system is produced in 2 insulation classes, an extra insulating layer is added to the insulation. For small pipes up to DN 40 both single and twin pipes can be supplied. Also a Quattro system for four pipes distribution system is available (up to DN 50).

The Ecoflex system as single pipe is available in the nominal diameter range from DN 20 to DN 90 (110x10) and as double pipe from DN 20 to DN 40. The material is transported in rolls, whereby each roll contains a length of up to 200 m for the smaller diameters and 100 m for the larger.

The medium pipe can be safely loaded up to max. 95°C for variable operating temperatures and with a pressure of 0.6 MPa. The lowest radius of curvature is given by the manufacturer as 0.25 - 1.2 m for the single pipes, depending on the nominal diameter, and for double pipes as 0.5 to 1 m. The minimum cover is 0.4 m for green areas up to 0.9 m for roads with a heavy traffic load.

For the connection of the medium pipe, the manufacturer offers 2 different connecting systems: the Wirsbo screw connections of the

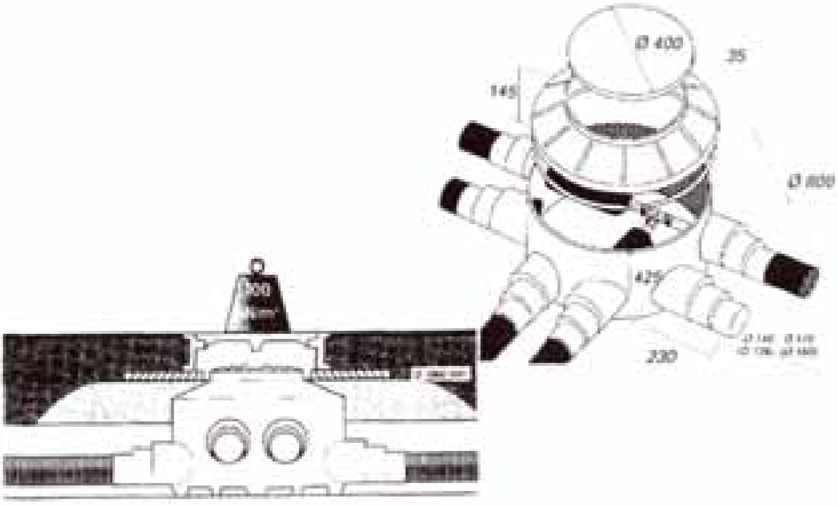


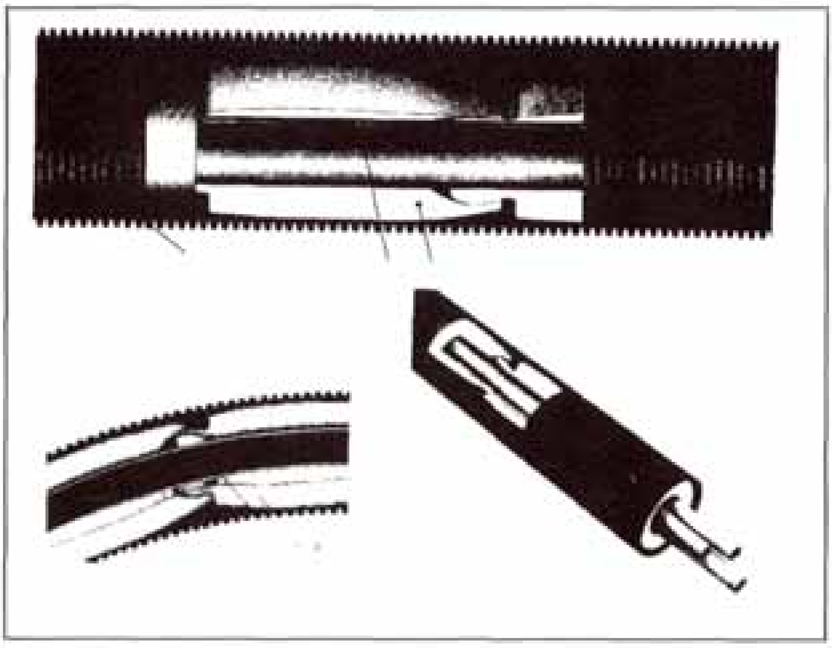
Figure 2.23: Inspection shaft Ecoflex with example of installation.

PEX-pipe manufacturer as well as the Ecoflex system. The Wirsbo joints are shown in Figure 2.22 for average-sized pipes.

Figure 2.22 shows an open T-branch on an Ecoflex pipeline. The medium pipes are joined with metal fittings and screws. As jacket pipe connector, divided half shells are fitted. They are laid around the branch, cemented and fixed with hose clamps. The thermal insulation is integrated in the wall of the half shells. The cavity between the medium pipes is not filled.

An inspection shaft is available for the Ecoflex system and this can be adapted to all nominal pipe diameters. In Figure 2.23 the construction of the shaft can be seen.

Figure 2.24: The Flexalen system 1000.



2.3 Pipe systems with non-PEX medium pipes

For the construction of district heating pipelines, an attempt has often been made to use thermoplastic pipe materials, since, compared to PEX, these would make it possible to weld the components. The following materials could be considered for this:

- PB Polybutylene
- PP Polypropylene
- PVDF Polyvinylidenfluoride

Polybutylene has proved successful for district heating pipelines and is being used today in the Austrian system Flexalen. Therefore, this system will be described in more detail in the following section. Although PP material has already been tested in district heating pipelines, it has too low strength properties for the normal operating temperatures of district heating. Regarding its physical properties, PVDF seems to be highly suitable, however, it is a too expensive material.

Before the system Flexalen is described more exactly, it should be pointed out that there are other manufacturers who have flexible pipe products and make their pipeline elements according to the specifications of the contractor, e.g. the company Star Pipe-A/S Dansk Rörindustri, Fredericia-DK. The products of the company Löffler, Worms-D, can be similarly classified and to some extent these form a separate programme and partly supplement the programme of the Flexalen company with special shaped pieces.

The Flexalen system

The Flexalen system is not a composite construction but is formed of individual elements. The medium pipe of the supply and return pipes is fitted in the protecting system (mechanical protection, thermal insulation and protection from moisture) perhaps only after assembly. The parts can be combined. The construction and function of the Flexalen system is shown in Figure 2.24.

The medium pipe consists of Polybutylene PB and it lies freely in the thermal insulation. In the case of double pipe construction, the outgoing and return pipes are installed in a common protecting pipe. Apart from the pipe walls, the pipes are not insulated against each other. Thermal insulation consists of round bodies fitted together with ball and socket joints forming a linked tube. The material is PUR foam covered by a lining.

A jacket pipe of PE provides external protection. It is corrugated to increase the flexibility. The medium pipe in its standard form consists homogeneously of thermoplastic Polybutylene PB. Today, in addition, a design is offered with an EVOH diffusion barrier. Only the medium pipe with diffusion barrier seems to be suitable for district heating pipelines. (The manufacturer itself recommends pipes without barriers for district heating networks.)

The program for Flexalen pipes extends from the pipe dimensions DN 20 to DN 125. Small pipes up to DN 65 (80) are supplied in bundles of 100 m lengths. Larger nominal diameters from DN 80 (100) are available in pipe lengths of 12 m lengths.

The limits for temperature loads are 95°C for variable operation, whereby the maximum pressure is fixed at 0.6 MPa, however for the larger pipe series it is 1 MPa. The radius of curvature is not permitted to be less than 1.25 m for material on rolls and at least 16 to 20 m for pipe sections of 12m lengths (large dimensions). The manufacturer prescribes coverage of 50 to 80 cm, depending on the load.

The standard connection for the pipeline material is welding for the thermoplastic material, whereby standard processes according to German standards DVS are applied, see Figure 2.25.

In addition to welded connections, there is also the possibility of using metal couplings, such as those applied for PEX-pipes. The transition from plastic to metal is also carried out with these types of component. The jacket pipes are connected with slip-on sleeves and shrink sleeves. Insulating shells are fitted at pipe joints as thermal insulation. At pipe branches either shaped parts are used insulated with PUR foam or the molded components are foamed on location, see Figure 2.26. Today, also preinsulated Tees, ellbows, etc., are available.

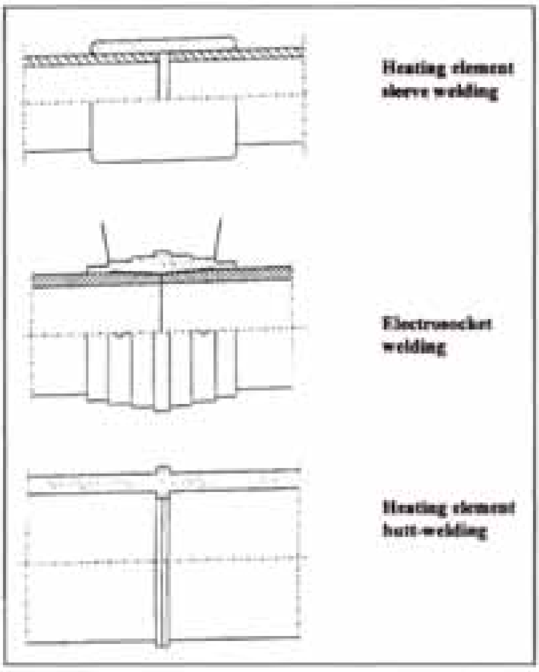


Figure 2.25: Standard welding joints for PB pipes.

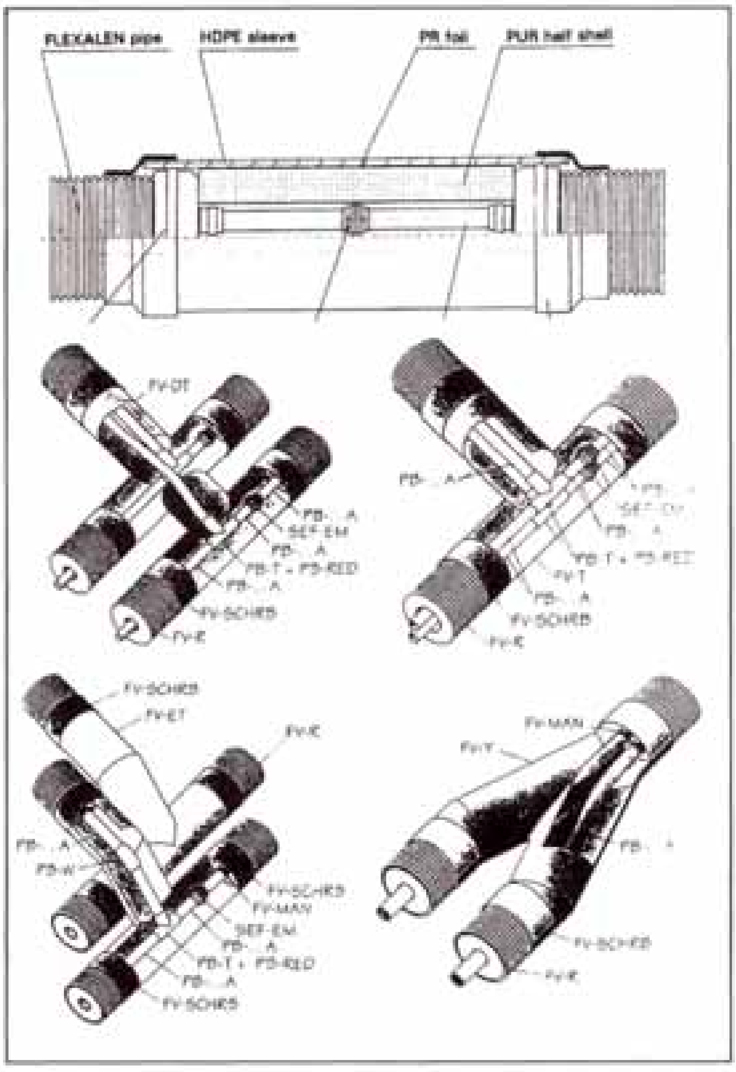


Figure 2.26 Flexalen sleeve connection as well as a selection of molded parts from the program.

2.4 Key features of plastic pipe systems

If one compares the properties of the plastic pipe systems described in detail in Chapter 2.3, one sees the typical picture of a new direction in development. There are numerous ideas and possible approaches that compete with one another and no general agreement has been reached, as is the case of the standardized pre-insulated steel pipes based on EN 253. A special position is only seen for the medium pipe of PEX, for which almost exclusively the standard pipe according to DIN 16892/3 is used. Only one manufacturer still uses PB pipes according to DIN 1696819. There is a lively further development of the technology for these systems.

The pipe nominal diameters, which can be delivered for a pipe system, give an impression of the chances of success that the manufacturers see for their pipe material. A few manufacturers only offer the smallest pipelines up to DN 25 or DN 40 in plastic, whereas other manufacturers propose pipes up to DN 80 and even larger than DN 100 as well.

The most important properties of plastic systems are summarized in Table 2.1. This is an indication of today's state-of-development, January 1999. It does not replace information in manufacturers' catalogues, which is continually changing.

A few points given in the Table are assessments that are only useful for comparing the systems, for instance regarding longitudinal water-tightness, flexibility and water absorption. Even when these terms are not exactly defined physically, they are important aspects in the use of these systems for the supply of district heat.

The flexibility of the pipe is an important property for the assembly of the pipeline. Up to now other important data on all products are missing, although they would be easy to determine. These include the torsional moment required to form a particular radius of curvature. In this way, the higher rigidity of the system at lower temperatures might also easily be described.

Table 2.1 consists of the 4 parts:

1. Measurements and material
2. Safe loads, construction
3. Pipe joints
4. Particular properties of the system

2.5 Advantages and disadvantages of plastic pipe systems in comparison to pre-insulated pipes

Today, preinsulated steel pipes provide a reliable system that fills the requirements of district heating operation. Primarily, cost considerations show advantages for plastic systems. As the selection of the most suitable pipe systems for a particular project always means a compromise between the different properties, the advantages and disadvantages of plastic and preinsulated pipes are shown in Table 2.2. In summary, it can be said that plastic systems have limits, in particular with regards to operating temperature and pressure and that they are only particularly suitable for small pipelines. On the other hand, they offer the advantage of a quicker and simpler assembly at the building site. Table 2.2 also presents a series of criteria that show the basic differences between the systems in respect to pipeline planning and operation.

Normally the diameter of a pipeline is defined by specifying its nominal diameter. The inner diameter of pipes is in general somewhat larger than their nominal diameter. Plastic pipes correspond to other standard dimensions than steel pipes. The plastic pipes have normally smaller inner diameters resulting for district heating pipes in only a small oversizing of the inner diameter, if at all. The plastic pipe manufacturers describe often the advantage of the pipe walls exhibiting a low friction factor compared to steel pipes allowing a higher flow velocity for the same pressure drop. This advantage is partially counteracted by the lower flow area of plastic pipes.

Table 2.1: The properties of systems with plastic medium pipes

Property	ABB-Isolpipe	Brugg-CALPEX	Isoplus-Isopex
1. Measurements			
1.1 Nominal diameter DN Single pipe from/to Twin pipe from/to	16 - 25 not in programme	20 - 80 (100) 20 - 40	16 - 80 (100) 16 - 50
1.2 Length supplied: max	200 m DN 16 100 m DN 20,25	384 m DN 20 to 88 m DN 65 (80) Twin pipe: 224 m - 88 m DN 20 DN 40	360 m DN 16 to 50 m DN 80 Twin pipe: 360 m DN 16 to 50 m DN 50
1.3 Wall thickness jacket pipe	2 mm	2.0 - 2.8 mm	2.2 - 3.0 mm (EN 253)
2. Material			
2.1 Medium pipe/Product	PEX	PEX DIN 16892/16893	PEX DIN 16892/16893
2.2 Thermal insulation density	PUR foam	PUR foam flexible 57 kg/m³	PUR hard foam 80 kg/m³ (EN 253)
2.3 Jacket pipe	PE-LD	PE-LD	PE-HD
3. Safe loads	(Set by manufacturer)		
3.1 Max. temperature for variable operation	80 C constant	max. 95 C	max. 95 C
3.2 Pressure (for Tmax,variable)	1 MPa DN 16(20) for 80C 0.6 MPa DN 25) const	0.6 MPa (1 MPa)	0.6 MPa
3.3 Min. radius of curvature	0.5 to 0.8 m	0.8 to 1.2 m Twin p. 0.9 to 1.2 m	0.8 to 1.4 m
3.4 Minimum cover	ca. 40 cm to 50 cm	60 cm (40 cm without traffic)	40 cm
3.5 Required thickness of sand bed layer	5 cm	10 cm	5 cm
4. Construction			
4.1 Compound	yes	yes	yes
4.2 Measures for flexibility	Smooth pipe	Corrugated pipe PUR foam medium hard	Smooth pipe PUR foam flexible
4.3 Diffusion barrier available	EVOH	EVOH	EVOH
4.4 Single/Twin pipe	Single pipe only	Single pipe; small DN Twin pipe as well	Single pipe; small DN Twin pipe as well
5. Pipe Joints			
5.1 Connecting technique for medium pipe			
5.1.1 Metallic/Welding	Press fittings with O-Ring-seal, DN 16 and 20 screw connections as well	Metal coupling Press fittings (Rehau) and screw fittings (Beulco)	Press fittings; screw connectors in special cases (Beulco)
5.1.2 Transition plastic/metal or connection to steel pipe	Metal connecting elements with weldable ends	Metal connecting elements with weldable ends and screw connection	Metal connecting elements with weldable ends
5.1.3 Branch of plastic pipe	Press fittings	Metal tee connector	Press fittings
5.2 Connecting technique for insulation and jacket pipe			
5.2.1 Jacket pipe connection	Metal half shells	GFK-half shells	GFK-half shells
5.2.2 Thermal insulation	PUR- foam on location	Shaped parts of PE-foam and PUR-foam on location	PUR- foam on location

Løgstør LR-PEX	Tarco PEX/FLEX	Uponor Ecoflex-Thermo	Fernwärme- Systeme Flexalen
16 - 80 (100) not in programme	16 - 40 not in programme	20 - 80 (100) 20 - 40	20 - 125 20 - 40
200 m DN 16 to 100 m DN 65 (90) Lengths 12 m DN 50	200 m DN 20 to 50 m DN 40	200 m DN 20 to 100 m DN 80 (100) Twin pipe: 200 m - 100 m DN 20 DN 40	100 m to DN 65 (80) from DN 80 (100) Lengths 12 m
no details	no details	1.1 - 2.2 mm	no details
PEX/Wirsbo DIN 16892/16893	PEX DIN 16892	PEX/Wirsbo	PB/Pipe Life
PUR foam medium hard 50 kg/m³	PUR foam flexible 60 kg/m³	PEX foam	PUR-element
PE-LD	PE-LD optional: EBA-Copolymer	PE-HD	PE
max. 95 C	max. 95 C	max. 95 C	max. 95 C
1 MPa DN 16/20 0.6 MPa from DN 25	1 MPa DN 16/20 0.6 MPa from DN 25	0.6 MPa	6 or 1 MPa
1 to 1.5 m	0.4 m DN 16 0.8 m DN 40	Single pipe 0.25 - 1.2 m Twin p. 0.5 - 1 m	1.0 - 1.25 m
40 cm	40 cm	40 cm to 90 cm	50 cm to 80 cm
10 cm	no details - stone-free	10 cm above/below 15 cm sides	10 cm
yes	yes	no	no
Smooth pipe PUR foam medium hard	Smooth pipe elastic (rubber)	Corrugated pipe soft PEX foam	Corrugated pipe, insulating elements
EVOH	EVOH	EVOH	Standard without: VS Type 500 optional with EVOH
Single pipe only	Single pipe only	Single pipe, small DN Twin pipe as well Quadruple pipes	Single pipe, small DN Twin pipe as well with outgoing and return pipes in direct contact
Press fitting DN 16-80 (110) screw con. 16 - 25 screw con. 32 - 50 compression coupling Wipex 50 (70) - 80 (110)	Metal- Press fittings DN 16 - DN 40	2 systems (Wipex system DN 20-DN 80(100) - Ecoflex system) DN 20-DN 80 (100)	Welding: - Heating element sleeve welding - Electrosocket welding - Heating element butt-welding
Metal connecting- elements with weldable ends; as well as shaped parts which can be welded in	Metal connecting elements with weldable ends and screw connection	Metallic screw and flange joints	Metal screws and flange joints
Connector and fittings	Metal tee with welding nipples	Connector and fittings	Welded fittings or shaped parts
Shrink sleeves of PE-HD	Assembly tee	Shaped parts for assembly with hose clamp	Slip-on sleeve
Insulating shells	Insulating shells also foam on location for T-branches	Integrated in shaped parts for assembly	Insulating shells in branch foam on location

Table 2.2: Advantages and disadvantages of plastic pipe systems compared with preinsulated pipes.

Criterion	Plastic Pipe Systems	Preinsulated Pipes
Safe Loads		
Pressure, Temperature	– **Limit necessary**	+ no problem
Construction, Design		
Available nominal diameters	– **small pipes**	+ all
Compensation	+ **not necessary**	– requires much effort
Thermal insulation, jacket pipe	o **identical**	o identical
Diffusion tightness (oxygen, water vapour)	– **tight to some extent**	+ tight
Assembly on site		
Building time	+ **short**	– long
Number of joints	+ **low**	– high
Flexibility (Adaptation to route)	+ **high**	– low
Weight	+ **low**	– high
Operational safety		
Corrosion in medium pipe	+ **impossible**	– possible
Leak detection	+ **not necessary**	– normal
Building costs	+ **lower than preinsulated pipes**	– high

3 Laying practice

In comparison to the building of preinsulated steel pipe systems, the laying of plastic pipe systems requires a completely different organisation of the work on the building site. In pre-insulated pipeline building, the engineering company must first dig a trench, which, for the whole time required for the assembly of the pipeline, has to be walked on and driven over. The trench can only be filled in again when the pipeline has been checked and sleeves completed, usually after a period of several weeks. With plastic pipelines, the pipeline assembly is reduced to a minimum. The pipe material, for instance, is taken from the roll directly into the trench, which can be filled in again immediately. Here the engineering work involved in digging the trench determines the speed of laying, whereas, in conventional laying, the assembly of the pre-insulated steel pipes is the time determining factor. *(Hower, new cold-laying techniques recently developed for steel pipes are changing this situation).*

Figure 3.1: Supply of a new housing area with district heating.

In pipe laying, a difference must be made between 2 situations:

1. Extension of the network in areas, which are to some extent already supplied with district heat.
2. The development of new housing areas.

In network extensions, the pipeline sections that have to be built are usually short house connecting lines, adapted to the pressure and temperature behaviour of the existing main-lines. There is usually no possibility of using pipe material which is suitable for lower pressures.

In new building developments the operating parameters can be selected according to the overall economic point of view, whereby the pressure rating of the pipe can to be taken into consideration from the very beginning. When a plastic pipe network is planned, it can, if necessary, be separated from an established steel pipe network, operated with higher temperatures or higher pressure, by means of a transfer station.

In new housing development areas with small dwellings, it is economic to lay the expected house connections (assuming that connection to the buildings is expected in the not-too-distant future) at the same time as the main line is built. District heating lines are then laid before road construction, but at the same time as other supply lines for water, electricity, etc. Figure 3.1 shows a development area with district heating lines; the bars mark the connecting points for the service connections.

In planning the routing for the pipeline, there are essentially 3 different concepts, which are shown in Figure 3.2. Example 1 shows clearly how flexibly the material can be used. Example 2 demonstrates how the connecting elements can be accessible for maintenance and control. Combined laying with preinsulated steel pipes is presented in example 3.

3.1 Planning and design principles

Compared to steel pipes, plastic medium pipes do not require compensation. The temperature expansion coefficient is indeed larger than for steel but the modulus of elasticity is considerably less. The thermal expansion is thus taken up by (elastic) deformation, without very high stresses occurring. The pipe system lies stable in the ground. In addition, there is the relaxation behaviour of plastic, whereby with time the material reduces the stresses by creeping. A certain space for free movement must only be provided for lines lying in the open.

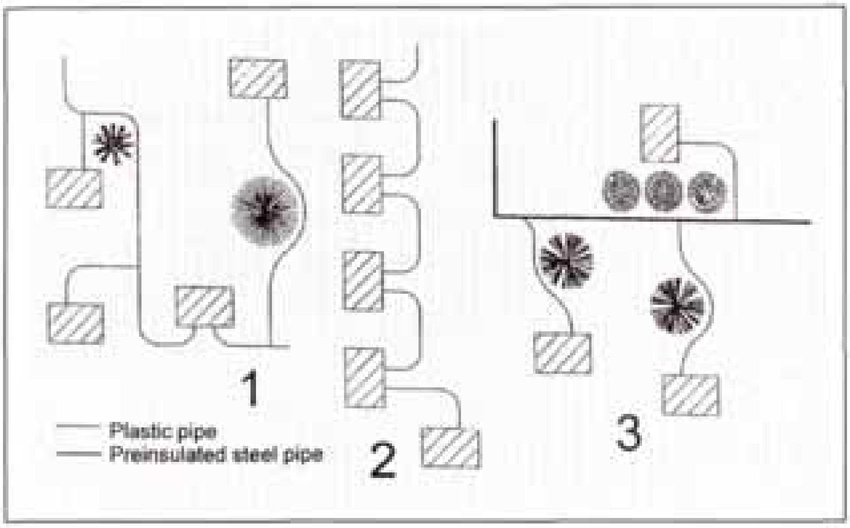


Figure 3.2: Examples of route planning
. Main and branch lines plastic pipes
. Looped-in laying (house to house connection)
. Combination of preinsulated pipes with plastic pipes.

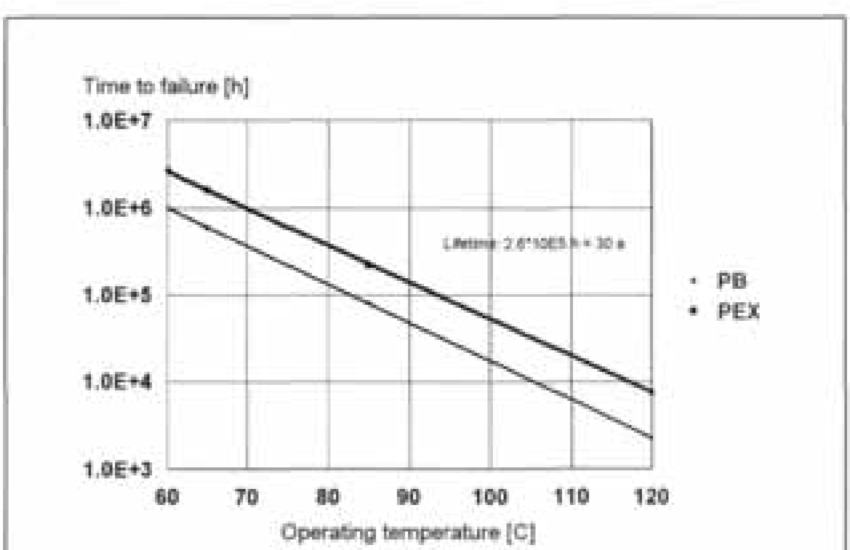


Figure 3.3: The service life of PEX- and PB-pipe material as a function of temperature [2,3]

Lifetime of the plastic medium pipe

Manufacturers give the lifetime of plastic pipelines as more than 30 years. However, the respective load temperatures are not always given as standard practice. In Germany, a lifetime investigation was carried out [4], which has been reproduced in brief here. From Swedish material investigations by Ifwarson [2, 3] lifetime curves for PEX and PB were derived. These curves represent lifetimes as a function of temperatures (based on Arrhenius), see Figure 3.3.

District heating lines are normally operated with variable outgoing temperature. Figure 3.4 shows typical temperature bins for the variation of outgoing temperature between 90°C and 60°C. To calculate the average temperature, which determines the lifetime, the following *Palmgren-Miner's* equation is used:

$$T_m = \frac{\Sigma a_i}{\Sigma \frac{a_i}{T_i}}$$

For the temperature distribution based on Figure 3.4, an average temperature of 63.5°C is given. A minimum lifetime of 30 years is usually required for district heating piping systems [1]. From Figure 3.3 it can be seen that at 63.5°C the lifetimes of PEX and PB are well over 30 years.

Figure 3.3 also shows which constant operating temperature the pipe material can bear. For PEX a constant temperature of over 80°C is allowed, for PB ca. 75°C. (Note: This is only true for the material of the medium pipes, not for the laid pipe system.)

The German supply companies are at present confirming a standard, which will allow a load of max. 90°C, variable operation and 0.5 MPa for a 50-year lifetime of the pipe systems dealt with here.

This calculation is based on a static safety factor of S = 1.8, compared with the normal factor S = 1.5 for steel pipes. The safety factor is increased for 3 reasons:

- uncertainities about the material on long-term behaviour

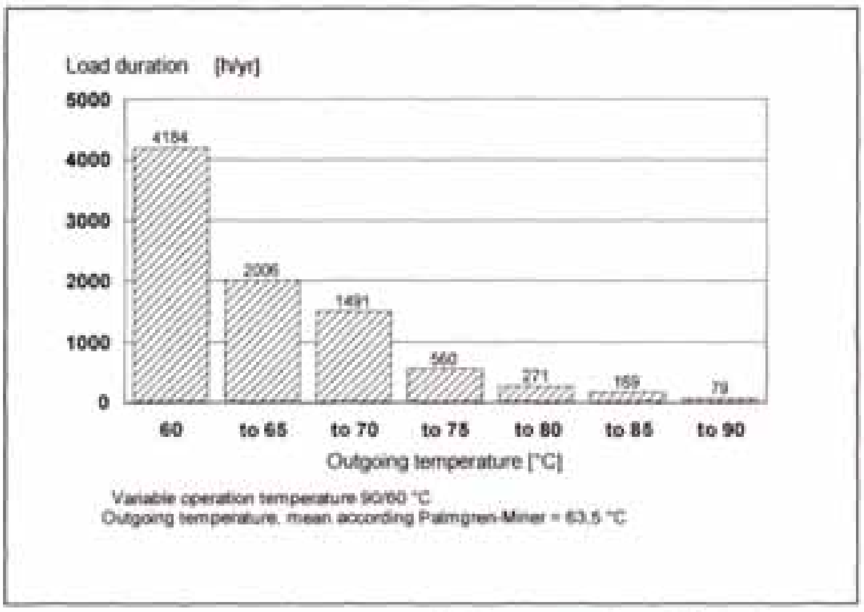


Figure 3.4: Temperature range for variable operation.

- to take into account the additional stresses due to bending
- because of the unknown behaviour of the material as a result of constrained thermal expansion.

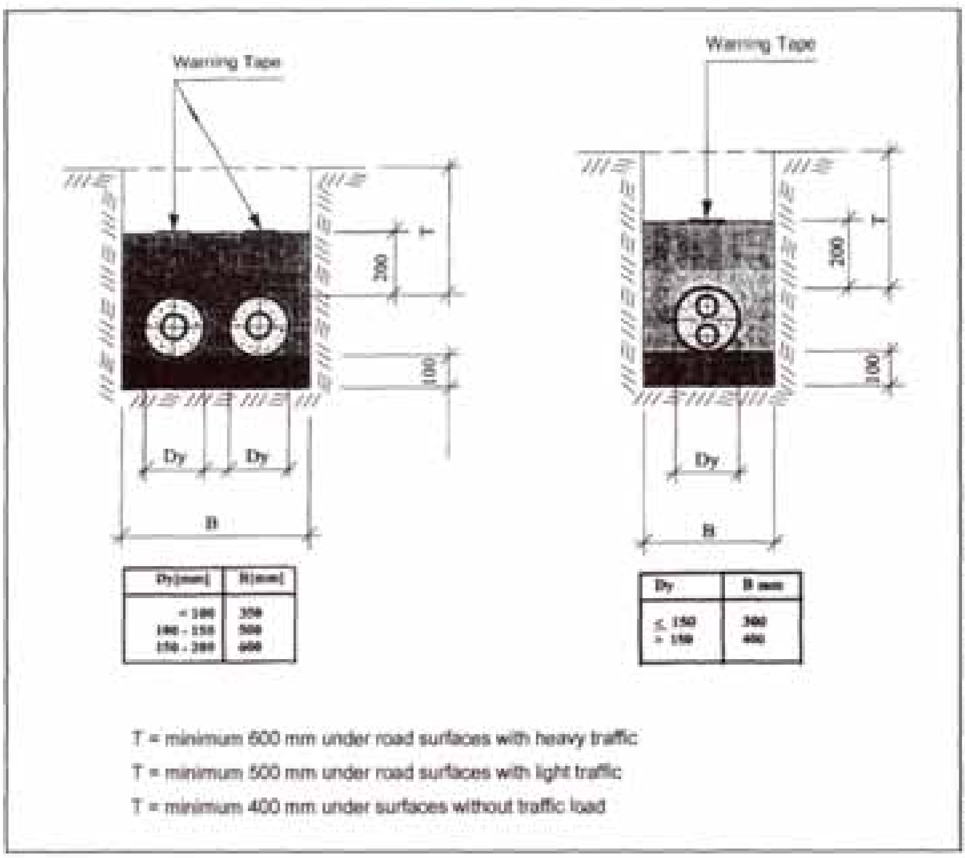


Figure 3.5: Trenches for flexible single and twin pipes according to the new Swedish laying rules [16].

Flow velocity and pressure loss

Flow velocity in plastic pipes should not exceed 2 m/s. This limit has been set by the manufacturers so that erosion of metal parts of copper alloys cannot occur. 2 m/s is a very high flow speed for small pipelines so that this limitation is not serious.

In regard to pressure loss, the suppliers of plastic systems insist that these pipes would have lower pressure losses than steel pipes, as they have a lower roughness. This cannot be generally asserted. Steel pipes of the same size (nominal diameter) usually have a larger internal diameter. The larger inner diameter compensates for the effects of the roughness. For instance pipes DN 40 in steel and plastic have the same pressure loss in practice.

3.2 Ground conditions and trenches for plastic pipe systems

Similar to preinsulated steel pipes, pipelines with plastic medium pipes can be laid in all types of ground. In the case of stony ground or rock it is even more important to prepare a clean sand bed for the pipes. Usually the manufacturers insist that the pipeline is embedded in a sand layer, about 10 cm thick (5 to 15 cm depending on the manufacturer), see Chapter 2, Table 2.1, line 3.5. An example how the plastic pipe systems are recommended to be installed in Sweden is given in figure 3.5. For twin-pipes the trenches can be smaller than for single pipes.

The jacket pipe of the system protects the thermal insulation from moisture in the ground. A temporary rise in the underground water level above the pipe vertex is allowed. However, the pipes are not suitable for laying where they will be continuously under water. It is to be feared that in this case the water vapour diffusing out of the medium pipe can no longer permeate through the jacket pipe to the outside and, with time, will collect in the insulating material. Increased heat losses will result from this situation.

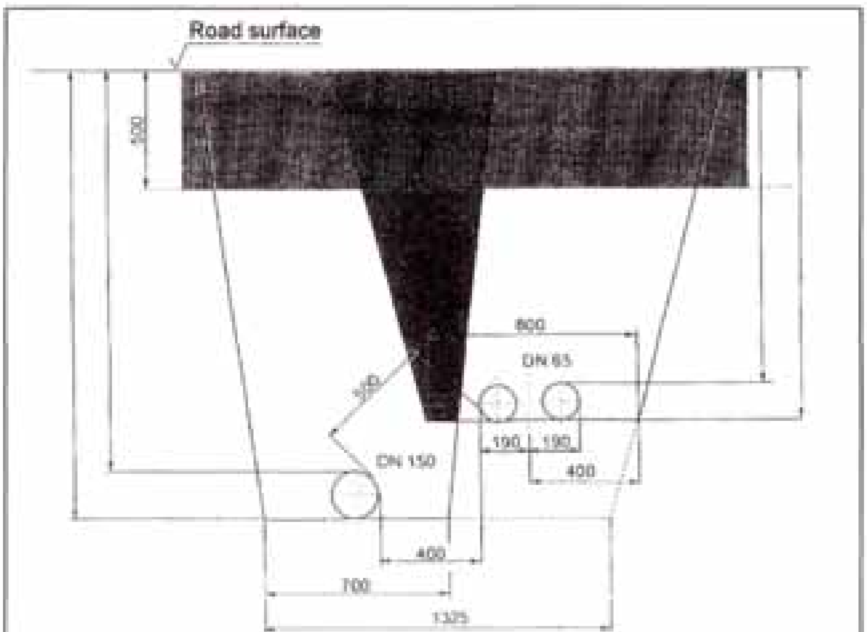


Figure 3.6: Diagram of the saving potential when laying district heating pipes at the same time as the water pipes (example MVV Mannheim, Germany).

In new housing development areas, the pipes are laid in sloped trenches. It is often advantageous to install the district heating lines together with others, e.g. domestic water pipes. In this way, the costs for engineering works can be reduced, as the total quantity of earth, which has to be removed, is less than when each operation is carried out separately. The shaded area in the middle of the drawing in Figure 3.6 shows the saving potential in

Figure 3.7: Two examples of service lines using plastic pipe systems.

building masses; it amounts to ca. 20 %. The actual value depends on each particular situation. Factors of importance include the depth required for laying water pipes to reach a frost-free area and the necessary separation between water pipelines and district heating pipes to ensure that the water is not heated above the allowed temperature.

The pipe trenches for plastic pipe systems can be just as flexibly adapted to the route conditions as in the case of electricity cables. The trenches can be kept narrow, as they do not need to be walked along when the pipes are laid. A changeover from the pipes laying side-by-side to one on top of the other can be done without any problem. Figure 3.7 shows 2 examples for service lines, utilising the advantages of plastic pipe systems when planning the route.

3.3 Laying techniques

The process of laying plastic systems is completely different from laying steel pipes. The most significant differences are the flexibility, the low weight and the pipe length, which can be chosen at will, see Figure 3.8.

Several manufacturers only offer plastic pipes to supplement preinsulated pipes for nominal diameters up to DN 40. For these small pipes the advantages of the flexibility and weight are particularly clear. They become less for increasing pipe diameter, as the thickness of the medium pipe walls increase considerably.

PEX-pipes with an inner diameter of 90 mm have a wall thickness of 10 mm. These pipes are already very rigid and are considerably more difficult to handle. It should be noted that the material rolls itself up again after being taken off the drums and so has to be treated to prevent that this happens. These difficulties increase at lower outdoor temperatures, as the flexibility is strongly dependent on temperature. It has proved advantageous to use devices for removing the pipe from the drums similar to techniques used in laying electricity cables or, in some special cases, to heat the pipe interior with hot air to make them more flexible.

For this reason, depending on the manufacturer, pipes greater than DN 65 are normally only offered as pipe lenths. Then more pipe connections are required and these need additional costs for material and assembly.

Figure 3.8: Examples from the laying practice.

The combined laying of plastic pipes together with preinsulated pipes seems to be particularly advantageous. Here, the most favourable material is used depending on the ground situation. In combination with preinsulated steel pipes it should be noted whether the pipeline is laid in a friction fixed or free-sliding zone. Connecting elements of plastic pipelines should not be stressed perpendicular to the pipe axis. However, axially, they are able to withstand stress. Therefore, it may also be necessary to fit branch lines with expansion cushions or to make the connection as a parallel branch, see Figure 3.9.

Insertion of plastic pipelines in conducts (closed construction)

In special situations, an alternative laying method is offered by laying in closed trenches, e.g. for crossing roads or similar barriers or for house connections through the front garden. The development of drilling technology has meant that drilling processes e.g. based on the principle of displacement (earth hammer) or as hydraulic boring (Flow-Tex and others) are now being offered by service companies. In the gas supply industry these drilling processes are no longer only being applied for crossing roads and house connections, but are even being used for longitudinal laying, Figure 3.10.

The installation of district heating pipes with their appertaining thermal insulation requires a check to be made on whether the traction forces required to pull the pipeline into the drilling lead to any overstressing of the pipe materials. The following estimation determines the allowable length of pipe using the example of the product Lögstör. To some extent, the other systems are not equally suitable for being subjected to longitudinal stresses due to their design, e.g. Ecoflex, Flexalen.

There are considerable uncertainties concerning the traction forces which can be applied to pipes. Depending on the type of soil, and the drilling process, various tunnel forms can occur and a flushing fluid can have a certain

Figure 3.9: T-junction and parallel branch of plastic medium pipes to preinsulated pipes.

lubricating effect. Actual measured values of traction forces on district heating pipelines are available from NWS, Stuttgart [5], and these also form the basis of the following considerations, see Figure 3.11. From this presentation, the function can be determined as regression line for the traction force of a pipeline with an outer diameter of 171 mm:

$$F = 0.162 \cdot l + 3 \quad [kN]$$

F = Traction force [kN]

l = Length of pipe to be inserted [m]

These friction forces, measured on a corrugated pipe (Flexwell-Fernheizkabel) were also applied to a smooth pipe, as it is well-known that frictional forces on corrugated and smooth pipes in the ground are of approximately the same order of magnitude. This traction force was calculated for other diameters assuming that the same stresses prevail for each unit surface area of pipe (which means the same as for each unit area of projection).

The cross-section of the medium pipes and jacket pipes are based on the geometry data of the pipe material. Both pipes are treated separately as far as their strength is concerned, as they are made of different materials.

The bearing strength of the foam is ignored. For the medium pipe of HDPE and the jacket pipe of LDPE, the following are used as stresses for comparison:

$$\sigma_{HDPE} = 10\ N/mm^2$$

$$\sigma_{LDPE} = 5\ N/mm^2$$

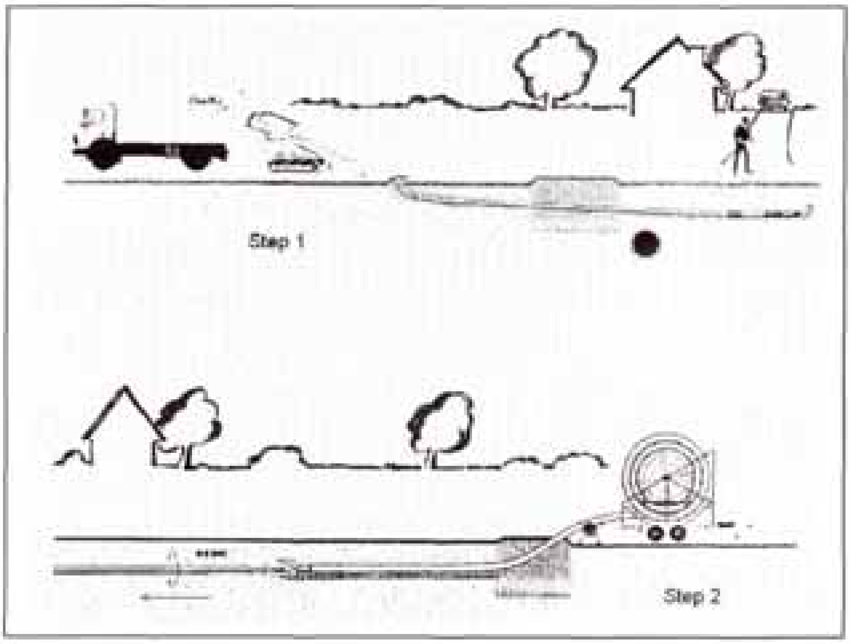


Figure 3.10: Hydraulic boring Flow-Tex. Step 1: Preliminary drilling with steering and position control. Step 2: Widening the boring and introducting the pipline.

In order to avoid both an overloading of the pipe material as well as too large deformations of the pipes, a safety factor of S = 1.5 is applied. With these assumptions, the allowable length of pipe that can be pulled into the drilling is calculated as given in Table 3.1.

A special problem in district heating networks is presented by the connections which have to be made to an existing supply pipeline. From an operational point of view, it would be desirable to include fittings for shutting-off , draining and venting. For cost reasons, they are however being more and more often omitted. Plastic pipes could offer an advantage here in the future, if they could be closed by squeezing, see Figure 3.12. This technique is already being practised for cold gas pipes. However, it has not yet been approved for a district heating application. Special material investigations will have to be carried out, for instance with reference to EN 12106.

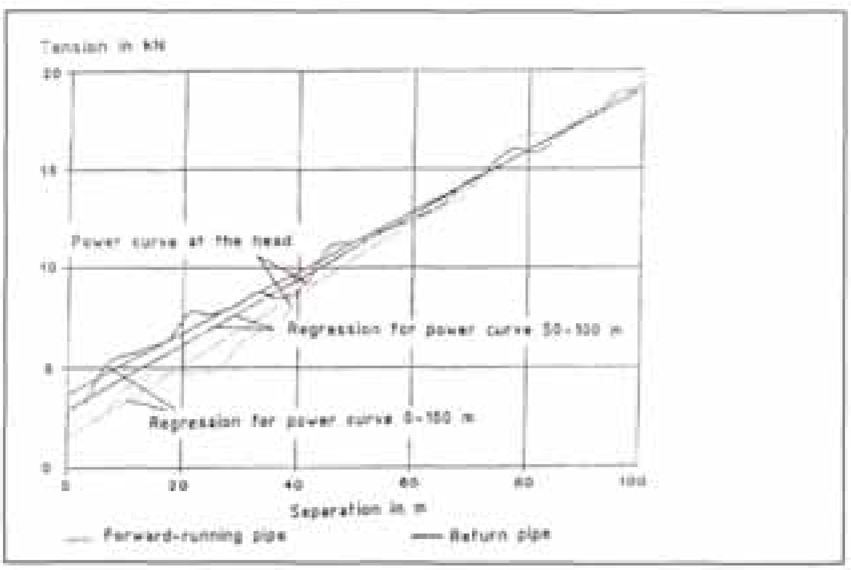


Figure 3.11: Traction force when pulling a corrugated pipe with outer diamter Da = 171 mm into a FlowTex-drilling.

Table 3.1: Allowable lengths of pipe LR-PEX of different diameters which can be pulled into a drilling.

d = medium pipe diameter
si = wall thickness of medium pipe
D = jacket pipe diameter
Sa = wall thickness of jacket pipe

Diameter DN	Pipe Geometry				Allowable traction	Allowable length of pipe to be pulled-in
	d [mm]	si [mm]	D [mm]	sa [mm]	[kN]	[m]
16	22	3.0	66	2.2	2.7	24
25	32	2.9	77	2.2	3.5	29
32	40	3.7	90	2.2	4.8	38
50	63	5.8	125	2.5	10.2	67
80	110	10.0	180	3.0	26.5	137

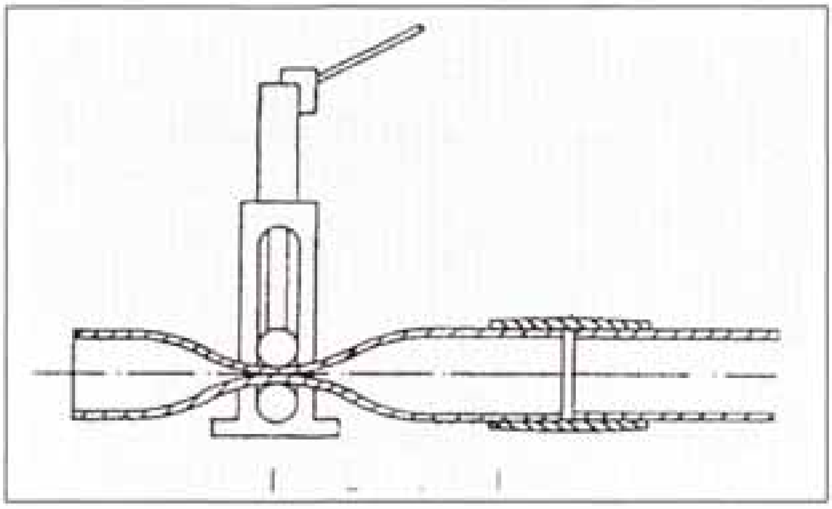


Figure 3.12: Squeezing of plastic pipes.

manufacturers' specifications for the load in the particular circumstances.

In areas used for pavements and parks, the requirements of the compactness of the trench filling are not as high as for roads. Here an attempt is made to simplify the process by washing in the bed material. However, this is only possible in sandy subsoil and ground that has good drainage.

3.4 Refilling and control

In principle a tightness and pressure test could be carried out after completion of the pipeline. However, there is no standard practice. Both the owner and the manufacturer can decide on whether or not such tests are to be undertaken. A tightness test will often be omitted, in particular when press fittings are used at pipe joints. A pressure test with 1.3 times the maximum operating pressure is seen as absolutely essential by some manufacturers, otherwise no guarantee is given.

If a tightness test is carried out in the pipe system, the shrink sleeves are installed later as the pipe connections must be seen for the tightness control.

The tightness test is preferably carried out with air, as a more exact control is obtained using air than with water. The pipes are closed and brought up to an inner overpressure of ca. 30 KPa. The pressurised air should be free of oil, i.e. the compressor should have an oil filter. All connecting parts are tested for tightness with a foaming liquid.

A pressure test on the pipeline, e.g. with 1.3-times the maximum operating pressure, is not mandatory. It can be insisted upon by the owners of the construction.

When filling in the pipe trench, first the prescribed sand bed is constructed. As far as possible, the soil extracted from the trench is used for refilling, so long as it complies to the regulations on road building. The total surface cover of the pipe must correspond to the

3.5 Experience from Swedish installations

In Sweden, some plastic medium pipe system were recently installed within a project for demonstration of conversion of electrical resistance heated buildings to district heating (see also Appendix C1).

3.5.1 House to house system

In one project - Munksund - the system connection was carried out as house to house connection with no branching in the ground. The pipe system was Ecoflex Thermo Twin. 1000 m of trenches connect 44 houses in a secondary system which in turn has been connected to a district heating main system by means of a substation.

The following installation experiences are worthwhile to be mentioned from these projects.

The pipe installation work was carried out by a single contractor who could optimise the complete work according to his own planning. The digging was done with a chain-digger which can make a trench 500 mm deep and 300 mm wide. This is a very small machine suitable for working in gardens as careful as possible. The machine could dig up to 5 house connections per day (125 trench meters), depending on the conditions with trees, bushes, other obstacles such as conducts, garages and entrance gates. For passing concrete garages entrances, alternative digging such as underground drilling or pipe pushing can be a cheaper and faster method. The average pipe costs were 990 SEK/m trench (124 US$/m).

The pipes are connected to the house system Cu-pipes in a small outdoor installation box - together with valves, energy meter and bypass. However because of the minimum radius being larger than 0.5, a deeper hole has to be dug below the box in order to direct the pipe towards vertical position. This can give conflict with other existing conducts such as electrical cable and drainage system. A special designed house coupling should allow to connect the pipe at a certain angle from the vertical and thus avoiding this problem.

The refill work is best done by the contractor, however, the fine surface restoration is very often preferred to be done by the house-owner himself in connection with the new planning or restoring of the garden architecture. Hence the contract with the house-owners should take care of the restauration wishes of the house-owner.

The air-venting of the pipe system in house to house systems is very important because of the many pipes sloping upwards to the house connections. Hence a suitable venting device should be installed at the substation making sure that the air can be removed at the start-up of the system.

3.5.2 *Traditional tree type installation*

In the second project - Häljarp -, 108 houses were connected with a combined Copper - PEX system to a recently built biomass boiler rated at 800 kW. In total 3000 m of pipes were installed with an average speed of 55 m per day. The Cu pipes were used for the largest dimensions of the main pipe, whereas all dimensions below DN 65 mm were made in LR-PEX (Løgstør). The pipe routing was done traditionally with the main pipes in the streets and service connection to each house. A very thin layer of sand was filled below and around the pipes, the remaining trench was refilled with the excavated material. Again only one contractor was responsible for all the pipe installation. The average pipe costs were 940 SEK/m (117 US$/m).

3.6 Commissioning

In conventional laying practice, 3 types of companies will be needed,

- a civil engineering company
- a pipeline builder
- an insulating company.

This can be simplified for the laying of plastic pipe systems so that only one company is needed on the building site. Hence the work can be organised more effectively, there will be no standstill periods and the utilisation of equipment will be better. It has proved being effective for the manufacturer to instruct personnel from the civil engineering company on the laying of plastic pipe systems. The company can finally complete all the work on the building site without having to call on other specialised companies.

In order to be able to take advantage of all possibilities for reducing costs with plastic pipes, there must be more intensive discussions between the utility representative and the contractors, and the system manufacturer should also be included if necessary. In this way, problems, which could become apparent during the construction work or even later, can be solved beforehand.

The following procedure has proved effective for producing a reliable estimate and hence for drawing up a favourable bid:

- Visit to the building site (route, working space, storage areas, building site equipment).
- Requirements of civil engineering works, piping system construction and restoring the surface have to be described accurately and completely.
- An overall plan of the project should be made and should be available to the bidders, building times should be discussed and an agreement made.
- The manufacturer of the system to be used must be specified. Furthermore the company's standards that are to be used have to be defined, e.g. concerning connecting techniques, sleeve techniques, branch techniques, house connections etc.
- The bidder should be required to visit the site before making an offer.

When the placing of orders is being decided, planning details should be discussed in depth and the results are to be written in an agreement.

A warranty for the new system of at least 5 years should be required. In addition to repairs to the pipeline, the guarantee should include excavating the ground and restoring it again and also any additional costs involved.

3.7 Installation of plastic pipe systems in comparison to pre-insulated steel pipe systems

The most important difference between plastic pipe systems and preinsulated steel pipes is their simple and quick assembly. For example, in one project in Germany it was necessary in a certain project to plan for 6 weeks for the construction of a preinsulated pipeline system. The same system with plastic pipes could be installed within a few days. This means that district heating pipe building for a small housing area can be completed in a week.

In pipe assembly, only simple tasks have to be carried out and these can be completed quickly. For this reason, as far as possible, only one company should be involved and responsible for optimising the building process itself. For small pipelines, these building companies use correspondingly light and manoeuvrable equipment, with which they can work efficiently. The pipe trench is kept narrow. It is dug with a small shovel-dredger, trench cutter or similar equipment, and, if possible, the excavated soil is piled up at the side. This is often the case as the pipe system with the necessary sand bed can be quickly installed and the trenches can then be filled in immediately. When necessary, particular points along the pipe route, such as pipe joints and connections are filled-in somewhat later. For this reason, roads are usually only closed for a matter of hours and road bridges are not required.

The pipe assembly is very quickly completed since only a few connections have to be made and these connecting points can be positioned where an open hole. The time-consuming assembly of a leak detecting system is not necessary and neither are the corresponding test measurements.

The outgoing and return pipes are laid in the ditch from above, without having to walk in the trench. Changes in pipe direction can be easily undertaken and, just as easy is the change from the pipes lying side-by-side to one-on-top-of-the-other and back again. There is no need for expansion zones around the pipes in the ditch, an operation which is most time intensive.

In the case of plastic systems, pipe joints are best carried out as press connections. Visual control of the joint is sufficient. They can be carried out using a special tool far more quickly than a welded connection on a steel pipe.

Whereas the laying of the pipeline is considerably easier for the plastic system compared to preinsulated pipes, branches require about the same effort for both systems. In plastic systems, branches are produced with formed pieces or with mounting components. In any case, the connections of the medium pipes have to be made and the mounting components have to be additionally insulated with PU-foam on location.

All things considered, the effort for laying plastic pipe systems is very much less than for preinsulated steel pipes.

4 System Technique - Application and Operation

4.1 System applications

4.1.1 Specification of plastic pipe system networks

The plastic pipes available for district heating purpose are limited to a few types that can operate at a high temperature of 90°C and a medium pressure of 0.6 MPa as shown in Chapter 3. Cross-linked polyethylene (PEX) and the polybutylene pipes meet these requirements. Hence for the use of plastic pipes system provisions must be taken so that the pressure limit conditions mentioned above are observed and kept under control for the total operational time of the system.

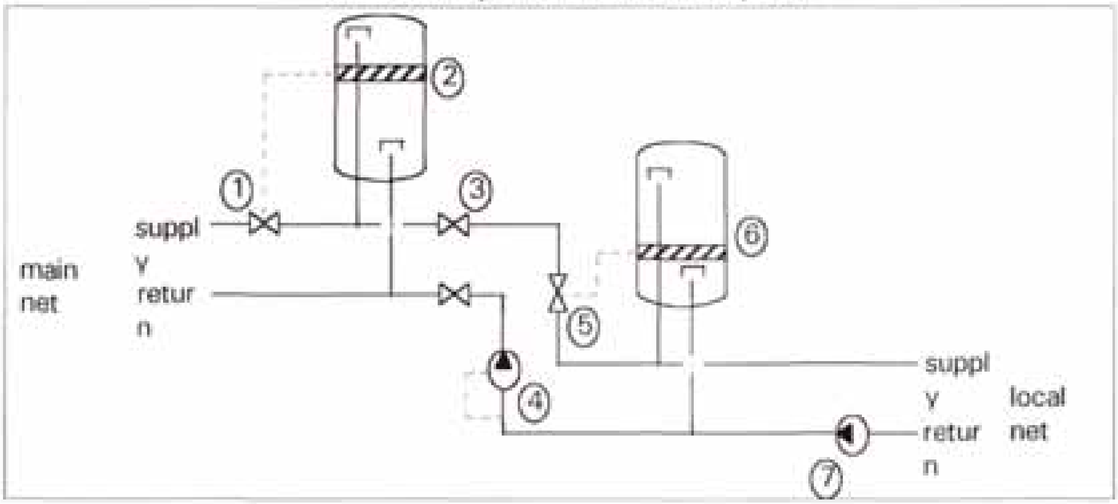


Figure 4.1 Principle of pressure transformer for separation of main from local net.

4.1.2 Connection to primary network, main types

4.1.2.1 Direct connection

Direct connection of plastic pipes to a district heating system is possible under the condition that the highest supply temperature and the maximum static pressure do not exceed the maximum parameters specified for the plastic pipe. Normally this means for PEX pipes, 0.6 MPa and 90°C. Also the plastic pipe must have an oxygen barrier applied.

The specifications must be valid for the whole district heating system. In most steel pipe systems the rating is specified to 1.6 MPa and 100°C – 120°C (or even higher in some countries). If the plastic and the steel system are directly connected, the *same rating must be applied for the entire system.* The plastic and the steel pipes can from design point of view be equal and mixed for the best economics. For example, smaller service connections can be plastic pipes, while the main pipes can be steel pipes.

Direct connected systems might be the ideal solution for smaller, so called *low temperature networks.* The design conditions for a system with direct connection of plastic pipes must take into account the customer installations. Due to the lower maximum allowed temperature, the heat exchanger in the customer substation for space heating will be slightly bigger. The commonly used brazed plate heat exchangers does not increase significantly the total price for a substation, should a few more plates be required. The pressure limitation requires a system where both the static head is maximum 0.6 MPa and the total dynamic pressure is within the design conditions. This puts some limits on the elevations that can be handled in a plastic pipe network.

4.1.2.2 Direct connection with pressure transformer

The relatively new technology of using pressure transformers for separating the local net from the main net in a district heating system can be applied when one would like to mix a plastic pipe system with a steel pipe system, 90°C / 1.6 MPa. Especially if for some reason the supply temperature of the system already is as low as 90°C, a further temperature drop can be avoided by using the pressure transformer instead of a heat exchanger.

The principle of a pressure transformer, also known under the name hydraulic switch, is shown in Figure 4.1. In two pressure vessels (2) and (6), the level of the boundary layer between the supply and the return temperature are controlled by temperature sensors which in turn control two pressure control valves (1) and (5) respectively. Pump (4)

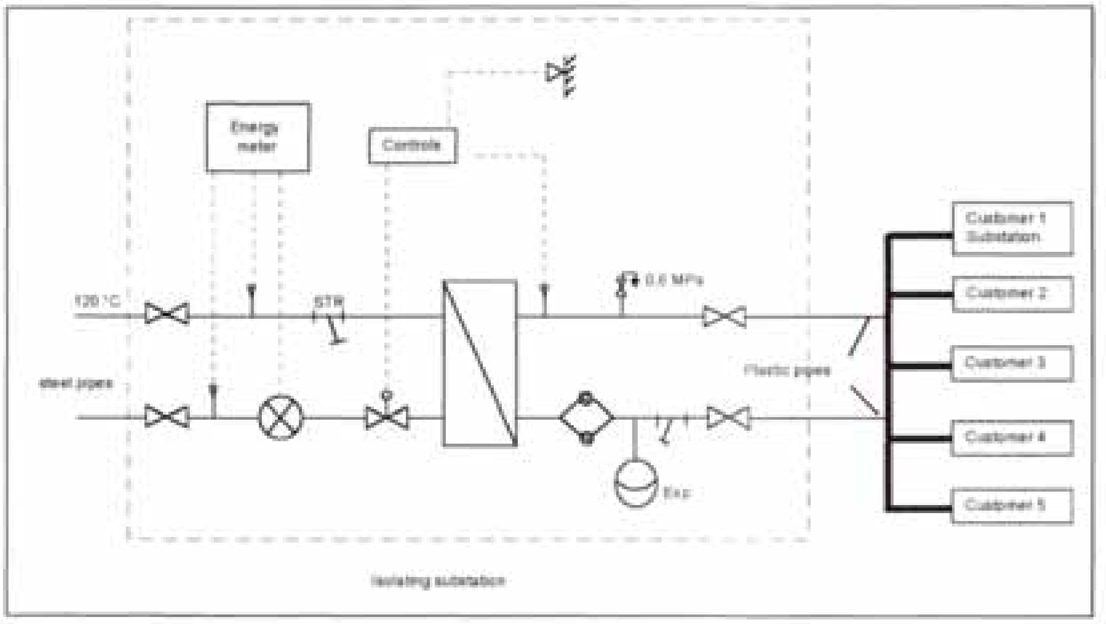


Figure 4.2: Indirect connection of a plastic pipe system to a steel pipe district heating system.

balances the differences in return pressure between main and local net and pump (7) provides circulation in the local net. The isolating valves (3) separate the primary from the local net in the case of emergency. Whenever such a situation happens, the water body is moving through the respective vessel avoiding fast temperature changes of the return pipes. The system insures that the local plastic pipe network cannot be overloaded.

4.1.2.3 Indirect connection with heat exchangers

The principle to use a heat exchanger between the primary district heating system and the plastic pipe system is the most common way to connect a local plastic pipe net to an existing steel pipe system (see Figure 4.2) at nominal operating conditions (1.6 MPa and 100°C - 120°C). The existing system usually can ot be operated with a lower supply temperature without affecting the existing customer installations.

The only safety equipment that must be included is a temperature limitation for the plastic pipe side of the heat exchanger and a safety relief valve that will limit the pressure in the plastic system, should the heat exchanger leak in the future.

The plastic pipe system will be designed independently of the steel pipes and operate as if it was a customer substation for heating only. Normally no other control system is necessary as long as the static head is below 0.6 MPa.

4.1.3 Connection to the heating plant

The installation within the boiler house or in the substation building for a secondary connection is normally carried out with steel pipes and steel equipment. The boiler circuit operates in such case at higher temperatures suited for safe boiler operation.

The comparably small systems that plastic pipes can be used for are often connected to the boiler without a heat exchanger. This means that the same water flows through the boiler as through the distribution system made of plastic pipes. With plastic pipes with diffusion barriers, normally no risk exists for boiler corrosion. However the corrosivity of the water should be checked regularly in order to be sure that the specifications of the boiler manufacturer being set.

The boiler circuit is connected to the plastic pipe distribution system by means of a shunt where the return water from the customer is mixed with the hot water from the boiler to provide the appropriate temperature according to the outside temperature.

4.1.4 Connection to customer

4.1.4.1 Two-pipe connection

In a pure plastic pipe system the distribution system is often connected to the building heating system without heat exchanger. Only a "Pump- & Shunt" is required. The domestic hot water is provided via a heat exchanger (Figure 4.3). Alternatively, a conservative connection may require heat exchangers for both the space heating and the domestic hot water demands.

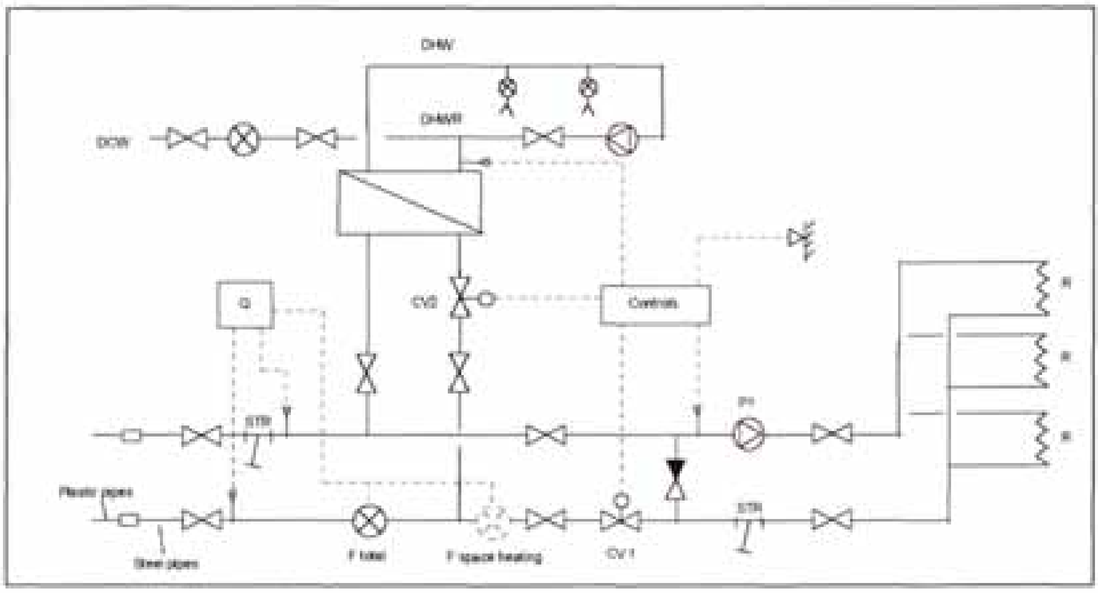


Figure 4.3: Customer connection by means of "Pump- & Shunt" for heating and via heat exchanger for the domestic hot water.

4.1.4.2 Four-pipe system

The four-pipe connection is often used between a few buildings (i. e. row houses) that have a common substation. The controls for temperatures are arranged for in the substation and the risers in each building operate as if they were in the same building. Balancing valves for the heating risers may be necessary. Some manufacturers offer special plastic pipes for distribution in four pipe systems: Four medium pipes integrated in one jacket pipe resulting in quite simple trench digging work. The pipe is available up to medium pipe dimensions DN 32 which is enough for heat and warm water supply for 10-15 single family houses.

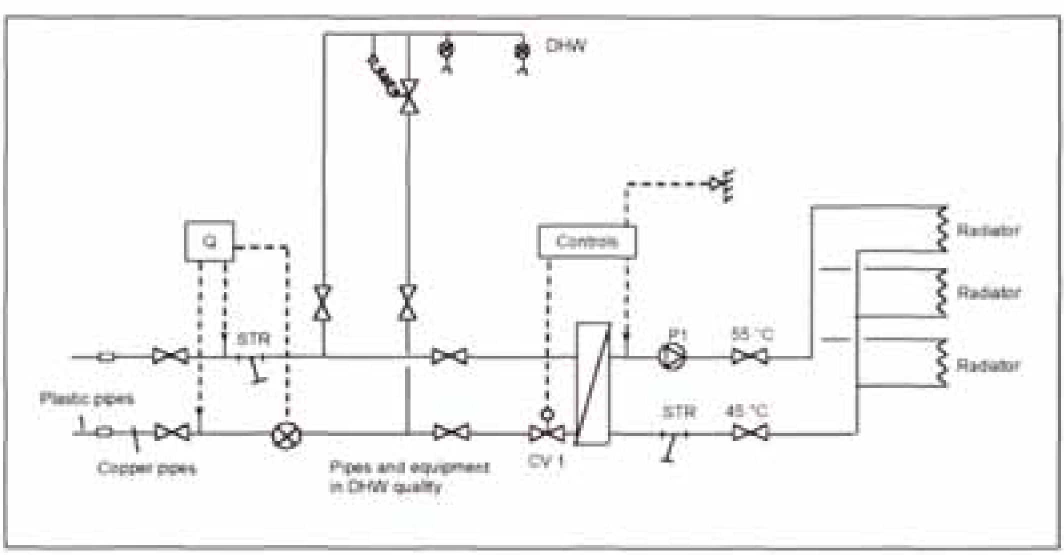
4.1.4.3 GRUDIS -system

The GRUDIS connection was developed prior to the introduction of the oxygen barriers. The heat carrier is the domestic hot water in this concept. This is possible when using drinking water quality of the plastic pipe material. The customer takes the DHW from the distribution system. If the temperature is too high, the DWH is tempered through a mixing valve.

Today, the GRUDIS connection is mostly used when working with so low net temperatures that the tap water temperature (e.g. 55°C) is difficult to achieve with a exchanger between supply and consumer pipes. This "low temperature system" is shown in Figure 4.4. The space heating system can be connected directly or via a heat exchanger.

If the district heating system is connected to existing buildings, the expansion tank and circulation pump. In new installations, floor heating or low temperature wall heating systems based on plastic pipes can be applied. In such systems also the radiator heat exchanger may be omitted.

Figure 4.4: GRUDIS 55°C/45°C (LT) customer connection.



Of course it is also today possible to use *unprotected* medium pipes in the GRUDIS system. In this case, the customer substation, the pipes and equipment in the "heat production" facilities, i.e. circulation pump and valves, must be of domestic hot water quality. When the customer has recirculation of the domestic hot water, a small heat exchanger with a self-actuating control valve would be installed to heat the circulating water to appropriate temperature.

4.1.5 Summary system applications

The PEX pipes available today with oxygen barrier can be used together with boilers and steel pipes on the conditions that the maximum pressure and temperature, 90°C and 0.6 MPa, is not exceeded. This applies to new systems that can be designed to these criteria from the beginning.

If plastic pipes are to be connected to an existing district heating system with standard design for temperature and pressure, 100 – 120°C / 1.6 MPa, a heat exchanger must be installed to separate the two systems. This separation unit is designed and operates as a normal customer substation that only provides heating. The savings in the utilization of the plastic pipe system must cover the cost for this heat exchanger station to justify the installation. In cases where the primary temperature is 90°C or below, pressure transformers can also be utilized.

Customers can be connected either traditionally via heat exchangers or by replacing the radiator heat exchangers by a pump&shunt system. In principle, also the DHW heat exchanger can be omitted through the GRUDIS connection, resulting in the system with the most simple connection between boiler house and consumer.

4.2 Operational conditions and strategies

Pipelines with plastic medium pipes are being installed in the following 3 areas:

- In small supply areas which often take heat from a local heating or CHP plant.
- In secondary networks, which are connected to main district heating nets and which are being operated with reduced pressure and temperature parameters.
- As small lines in existing supply networks, when pressure and temperature are sufficiently low. This combined laying is only used to a significant extent in Denmark.

There are other known uses, for instance, pipes for hot water supply or in chemical plants. However, these will not be dealt with here.

4.2.1 Recommended operational conditions

Networks with plastic pipes should be operated with water temperatures, which are as low as possible. This increases the lifetime of the pipes. In Section 3.1, Figure 3.3, it was shown how the life-time increases with lower operating temperatures.

Usually district heating networks are operated with variable supply temperatures to reduce heat losses. The maximum operating temperature is only necessary for a few hours of a year.

If one compares a plastic pipe network, which is operated at a constant temperature of 80°C with one with supply temperatures varying between 90/60°C, in the second case the calculated lifetime is increased by a factor of about 4, see Figures 3.3 and 3.4.

Plastic pipe systems have to be protected from overloading caused by too high temperatures or by too high pressures. A precaution against exceeding the allowed temperature is provided by controls at the heat production plant. In secondary networks there is a temperature limiter at the heat exchanger so that it is impossible to exceed in particular this limit. Exceeding the pressure limit is also impossible because the plant is always equipped with safety valves.

The well-known regulations, for instance [14], are valid for the treatment of district heating water. Demineralised water is preferred, as long as the costs and effort are acceptable. From the operation of district heating networks with plastic pipes, it is well known that circulating water behaves differently from water in steel pipes. After commissioning, relatively large quantities of impurities can be detected. The impurities decrease with time and, after about two years of operation, there is no difference from water in steel pipe networks [10]. For that reason, circulating water in plastic networks has to be filtered more intensively after commissioning [9].

In Finland, it has been proved to be sufficient to integrate generously dimensioned filters in the circuit to clean the water at intervals of 1-2 months at the start of operation [10]. Fine mesh sizes down to ca. 10 µm are used.

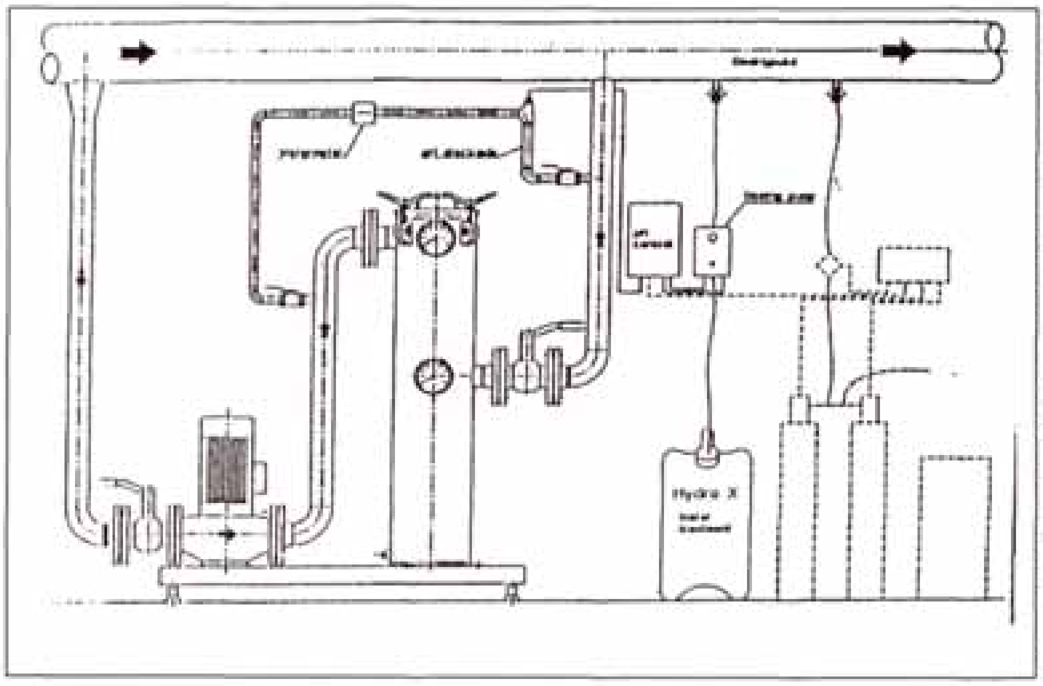


Figure 4.5: Branch flow filter for district heating network. (Diagram from HECO company).

In addition to the supply of municipal heat, there are other areas where district heating pipes in small dimensions are being built. These include private building associations, public building administration sectors and the armed forces. According to the manufacturers, these are important purchasers of plastic pipe systems. Experiences of the frequency of breakdowns in these areas are only available to a limited extent. However, from the increasing sales of plastic pipes, it can be assumed that the operating results are generally positive.

Of the total length of public district heating networks in the European countries, Finland, Germany and Sweden, less than 1 % consists of plastic pipe systems. From the Finnish statistics on failures [12] it can be stated that these systems show failures which are less than average. Particular experience with plastic pipe systems are available from the utilities Lahti, Finland, where various plastic systems (but without oxygen barrier) have been installed since the end of the 1960-ies. Plastic pipelines are reported to be extremely reliable in the respect to leakage[10]. In general, failures can be repaired at low costs.

Similar are the experiences from Sweden and Germany. In Sweden, plastic medium pipe systems have been installed since the early 1970-ies, for the most in local block heating systems. In general, systems which are properly built following the manufacturers' instructions and designed by consultants, experienced in plastic pipe systems have been operated without failures. However, in some cases, corrosion problems due to the unprofessional use of unprotected pipes in systems installed before 1986 have been very extensively discussed. For the reason of overcoming this problem, the GRUDIS technology (see Chapter 4.1.4.3) has been developed. As it was the case in Finland - the Ecoflex system was the most common system used in Sweden.

For the Danish industry, complete filtering stations have been developed and these are now being built, see Figure 4.5. These filtering stations clean the district heating water in a branch flow (ca. 5 to 15 %). The water flows through a magnetic separator (Fe_3O_4), is filtered and set at a particular pH-value. The plants work more or less automatically and can be easily taken out of operation, e.g. for refilling with chemicals, as they are parallel to the main pipeline. Microbial growth has been detected in plastic pipe lines [11]. Although these microbes in district heating networks are less serious than those in domestic hot water supplies, even so they are not desirable. They encourage the formation of mud and, on one occasion, a mixture of inorganic and organic impurities gave rise to hydraulic difficulties. Such problems cannot occur with the filter methods described above.

4.2.2 Failures

Statistics on the frequency of failures in the various pipe techniques have been produced by public utilities. From these statistics no reliable statement on plastic pipe systems can be made, as plastic systems only make up a small share of pipe used today and are therefore not included separately in statistics. Usually they are contained in the collective position "other laying techniques". They are only described in more detail in the Finnish statistics.

Although there are no firm numerical data from Denmark officially published, some information from the Danish Industrial Association, as well as individual utilities and manufacturers, is available, showing that more than 50 % of the smallest pipelines today use plastic medium pipes. Thus, plastic pipelines in existing networks show a higher share than in the other countries. The operating experiences are good, the failure rate low [15]. Also from Germany the general impression is reported - based on the limited use of plastic medium pipe systems - that plastic pipe systems are reliable.

Summarising it can be said that plastic medium pipes systems have proved to be reliable and have shown only a low failure rate in operation up to now. The pipe connections and the necessary system components have also proved themselves to be reliable in the period of operation to date.

4.2.3 Maintenance and repairs

If the plastic pipe system is a secondary network, then the substation connecting to the main net should be considered to be part of the plastic pipe system. This substation needs of course some maintenance which has to be very well documented. For example the function of valves and pumps might be controlled regularly and filters must be cleaned. In Sweden, the standard amount of maintenance work for such devices is 2 % of investment costs per year.

As to plastic pipe systems, if the pipes are buried without joints in the ground, all fittings should be placed in such a way that they are easily to be inspected. Experience shows, that the amount of maintenance work for the pipe system in this case is rather low (FVF 1998:9). If the system has fittings buried in the ground such as for the connection between steel- and plastic pipes and for branch and service connections, the maintenance effort is considered to be comparable with that of steel pipe systems. Much maintenance and repair work can be avoided by making an adequate initial inspection of the system in connection with the installation and before burying the fittings. In early projects, the pipe systems were pressurised with water at 30 % higher than design pressure. Nowadays, this procedure is in most cases replaced by a 30 KPa air pressure test.

In the house station, the plastic pipes are very often connected to copper pipes. All these connections should be inspectable and usually no maintenance should be necessary in recent systems (older fittings needed in some cases a readjustment after a couple of years). Maintenance work is mostly due to the conventional installation components for the house station.

4.2.4 Status control

Plastic pipe systems are usually installed *without* a signal system for moisture detection and other controls. However, in many cases, a signal cable for information is laid down in the trench, very often just in case of future use.

Depending on the pipe system, moisture penetration of the insulation can damage the insulation of the whole pipe section (e. g. in Ecoflex systems with PEX insulation). However the house to house connections with end sections bend upward in each house. This prevents water from entering the house. The systems with PU-insulation limit the spread of water by means of their design. Hence a moisture detection system in combination with plastic pipe systems is not considered to pay for itself (presuming that there is no damage to the medium pipe itself).

However, as already stated above, a larger area small mesh size filter in the main system and smaller filters at the house stations might be a very useful provision for regular control of the water quality and indications of eventual corrosion.

4.2.5 Summary – operational benefits of plastic pipe systems

The experience from the operation of plastic pipe systems, also in combination with steel pipe systems is altogether positive.

Small trenches - Plastic pipe systems use small trenches and allow a maximal use of refill material. The depth of the trench must be chosen according to the expected loads. In gardens and other areas without traffic load, the depths can be limited to 40 cm above the pipe. The sand bed filling is recommended to be 5 - 15 cm around the pipes

Combination of plastic pipe and steel systems - is considered to be unproblematic if plastic medium pipes with oxygen protection are used.

Co-installations - with other ground buried conductor systems such as cables and city water can appreciably lower the total contract work costs. Hence in many projects, especially in new development areas, a single contractor can do the job and costs can be saved by co-planning and co-installation of different distribution and duct systems.

Low number of joints - plastic pipe systems minimise the number of underground joints and therefore the number of risks for failures.

Pressure test with air - plastic pipe systems are nowadays pressure tested with an over pressure of air (0.3 bar). This simplifies the process for bringing the system into operation.

Plastic pipe systems are available as Twins (up to DN 40) and for some makes also as Quattro systems (up to DN 32) – allowing the use of small trenches rather than large sizes. However it should be mentioned that both steel pipe and copper pipe systems are also available as Twins in smaller dimensions.

Venting - is very important. There should be a main venting system (type Spirovent or similar) installed in the main distribution system). Further venting valves should be installed at high points near the consumer stations.

Moisture detection systems are not necessary - because of the low probability and the relatively poor consequences of an eventual untight jacket pipe, the signal system was not found to be worthwhile.

Water filtering systems - are good practice for detecting abnormal amounts of oxygen and risk of corrosions in existing steel components.

Direct connection - of plastic pipe systems is assisted by the low operational pressure and temperature of the system. Direct connection can be accomplished either to the house radiator system or to the potable water system (Grudis system).

The Grudis-system - allows working with the lowest supply temperature because the potable water is supplied through the plastic pipe main without heat exchanger.

The pressure transformer – is a new component enabling the separation of systems with different pressure limitations, such as steel- and plastic pipe systems without temperature degradation.

Maintenance efforts - are estimated to be equal to steel systems so far as heat production systems and consumer stations are concerned. As to the pipe systems, the maintenance costs of plastic pipes are considered (or rather - because of lack of feedback - *estimated*) to be lower than that of steel pipe systems.

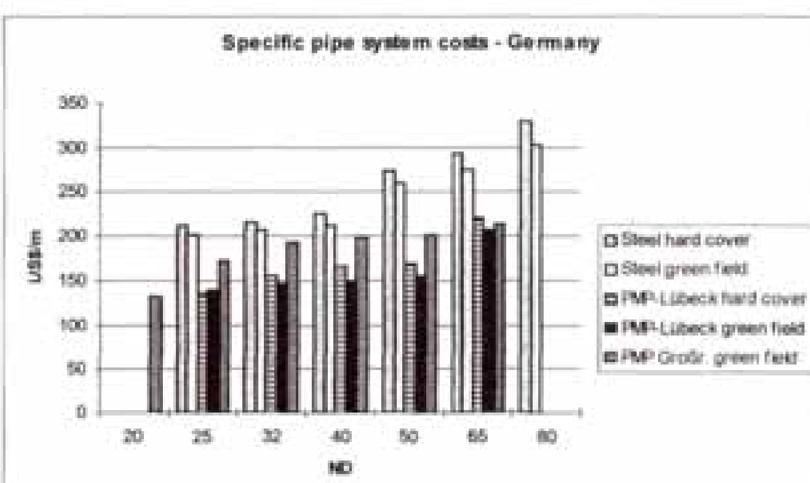
5 Economical system rating

A general understanding by experts working with design and operation of heat distribution systems is that plastic pipe systems can lead to lower costs than preinsulated steel pipe systems in certain specialized applications. However, an objective part of this is not so easy to establish. The following reasons for this can be mentioned:

- Plastic pipe systems must be operated at a lower temperature and pressure standard compared with steel pipe systems. If such a standard would be applied on steel pipe systems, also such systems can be made cheaper and - in small dimensions - made flexible.
- District heating design concepts differ widely according to traditions and practice developed in the different countries. A special type of design concept, e. g. that might fit the operational conditions of plastic pipe systems, might be easy to be applied in one country and might be difficult to achieve in another country. Therefore costs for the same system can vary from country to country according to the established practice.
- Cost of supplied material and more importantly of hired manpower are very often objects of contracts and can vary widely according to local and seasonal conditions, availability of manpower, size of the project, etc. If it is difficult to compare costs for different type of systems at different places within a country, it is still more difficult to compare them between different countries. Hence statements such as a specific system is cheaper than another should be treated very carefully and are difficult to generalise.
- Manufacturers and contractors are for reasons easily to understand very reluctant to share cost figures. Hence the figures mentioned below are chosen from project examples for illustration purposes. ***Do not expect that they will apply automatically to any other project.***

A conclusion of the above comments about pricing is that price comparison will only be based on examples from some countries. They can help to understand advantages and limits of plastic pipe systems compared to other types, but must be handled very carefully if general conclusions are to be drawn.

Figure 5.1: Cost per meter trench for plastic pipe systems from three German plastic medium pipe projects in Völklingen and Lübeck in comparison with established costs for steel pipe systems (1996).



5.1 Cost comparison plastic pipes vs traditional steel pipe systems

In the following some costs examples for the application of plastic pipe are presented. These examples are derived from projects realised in different countries, i. e. Denmark, Germany, and Sweden. See also project examples in the Appendices C1-C3.

5.1.1 Germany

From Germany, experience is available from three projects in Völklingen, Großrosseln and Lübeck. It should be mentioned that the project undertaken by Fernwärmeverbund Saar in Völklingen and Großrosseln were undertaken by a contractor inexperienced with plastic pipe systems, whereas the project in Lübeck was performed by an experienced Danish entrepreneur. A summary of the total costs of the installed pipe system in comparison with usual costs of steel pipe systems is shown in Figure 5.1 [4].

From these examples it can be seen that the system costs depend widely on local conditions. The experienced contractor installs the system at lower cost than an inexperienced. But both contractors achieve lower system costs with plastic pipe systems compared to steel pipe systems at dimension up to DN 65.

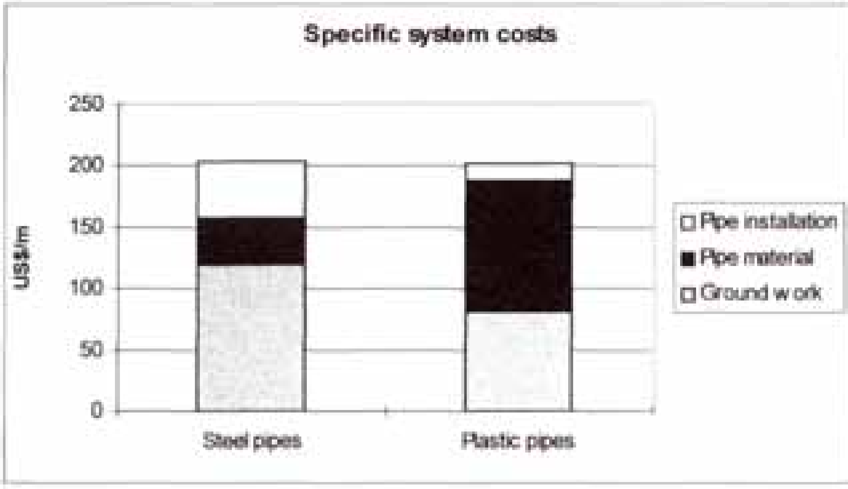


Figure 5.2: Specific system costs for projects of Fernwärmeverbund Saar: Mixture of all pipe sizes between DN 20 and DN 80.

Exchange rates:

1 US$ = 8 SEK
1 US$ = 1.7 DEM

A further analysis based on the cost analysis of Fernwärmeverbund Saar was made by the Stadtwerke Mannheim. A "Time- and Cost Analysis System" was used for comparing both steel pipe and plastic pipe systems including dimensions up to DN 80.

The result was that lower civil costs for plastic pipes was verified, but it was partially counteracted by rather high material costs for the dimensions used in the project. It is obvious that a part of the lower system costs at Lübeck is the result of lower material costs supplied from the Danish contractor. It is expected that with a growing plastic pipe market in Germany, the plastic pipe material will get cheaper and the cost advantage of smaller plastic pipe systems will become more evident.

5.1.2 Sweden

An extensive cost comparison was performed in 1990 [32] and recalculated 1993 [24]. In this study PEX medium pipes without oxygen protection were considered, but the price contribution of the oxygen barrier can be neglected for the purpose of this analysis.

It gets obvious, that the trend seen in the Danish and German projects is also seen in Sweden. Total pipe systems costs of plastic pipes are cheaper than of steel pipe systems in dimensions up to DN 65 and equal or more expensive above that. However, the pipe material is only cheaper for the smallest dimensions up to DN 32.

For this reason and also for the reason of total cost reduction, plastic pipes are very often designed in small systems with adequate pressure head for a allowable flow of 2 m/sec compared to steel pipe systems 1m/sec. The designer is therefore allowing a pressure drop as large as 500 Pa/m, allowing the use of smaller dimensions and therefore to save further costs.

In a recent study [33] a similar cost comparison was based on prices from a bid of a contractor and compared with typical costs from the Swedish District Heating Association for steel pipe systems [34].

Comparison of the cost figures for 1993 and 1997 indicate a price increase especially for larger dimensions, for both types of pipes.

However the cost difference for installed systems is obvious also in the 1997 figures: The smaller the dimension the larger the relative gain. The smallest pipe system are about 30% cheaper and the largest considered system DN 65 is about 5% cheaper than a steel pipe system. A comparison with the prices of German systems gives a general tendency that Swedish pipe system prices are about 20 - 30 % lower than the prices indicated in Germany.

So far the price comparison does not include branching and service connections. These costs depend on the system design. For traditional design with the mains in the streets and T-branches for service connections, the branching costs are considered to be higher for plastic pipe systems than for steel pipe systems. However, if the flexible plastic pipes are connected from house to house, no T-piece branches are involved. Instead one has to take into account the costs of generally larger pipe dimensions and of larger trench lengths for house connections.

The total final system costs are a function of the system design. For example some DH utilities prefer to connect detached single family houses in a traditional way with all branches in the streets having by that way good access to all critical points. Other prefer to make a deal with the house owners and give them some discount for the connection costs by being allowed to draw pipes through the gardens. Hence the final system costs must be derived from realised designs for given projects.

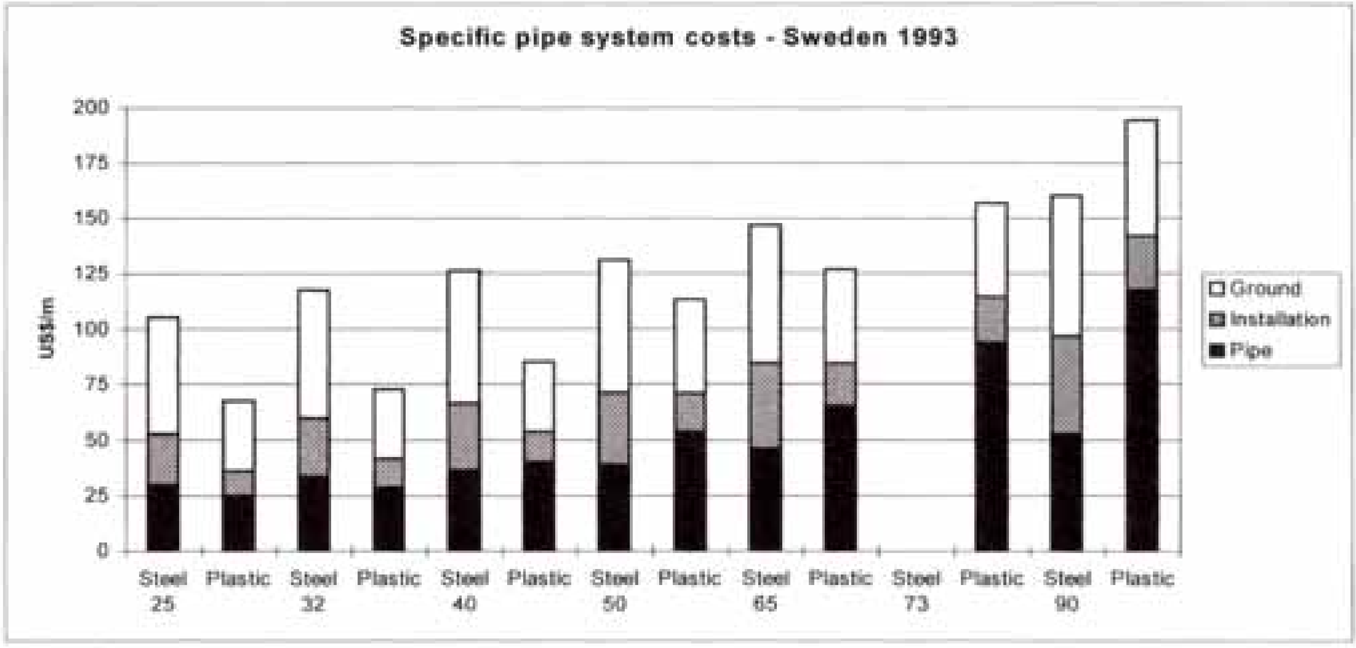


Figure 5.3. Cost comparison for pipe system costs in Sweden, 1993. Easy to dig green field. (Costs for branches and T-pieces not included.

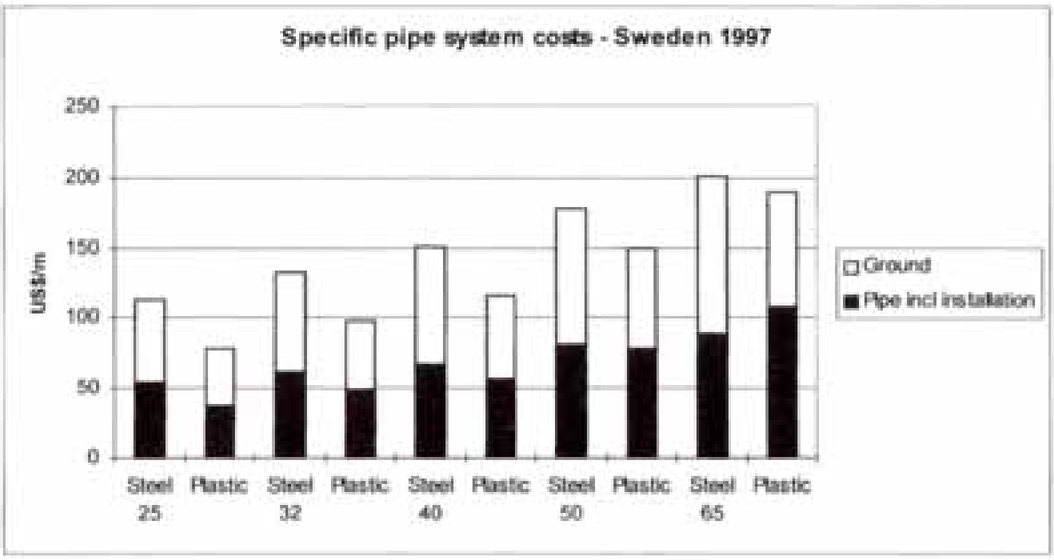


Figure 5.4: Cost comparison for pipe system costs in Sweden, 1997. Easy to dig green field. (Costs for branches and T-pieces not included).

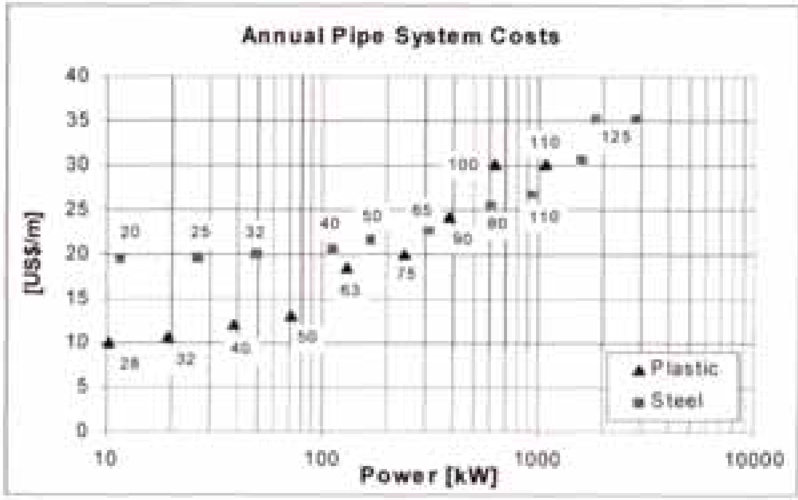


Figure 5.5: Example of comparison of total annual costs of two pipe systems. Plastic pipe system 90/65-50°C. Steel pipe system 100/65-50°C. Including depreciated investment (30 years, amortisation time, 6% interest) and heat loss costs (31.3 US$/MWh). From [35].The comparison holds for suburb-areas with pipes insulated according to series 2 standard.

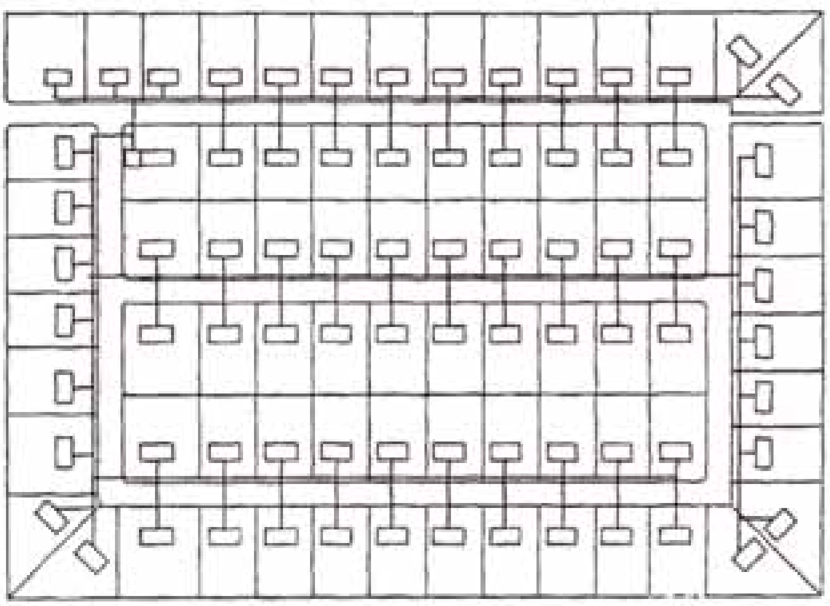


Figure 5.6: Group of dwellings connected to a central heating plant.

5.2 Economic sizes of plastic pipe networks

In a study [35] a general attempt was made to compare costs for the following two systems by calculating the total annual costs for two systems:

- Steel pipe system with 100/65 - 50°C
- Plastic pipe system with 90/65 - 50°C (temperature adjusted supply temperature assumed in both cases).

The following parameters were chosen: Amortisation time 30 years, real interest 6 %, Energy (heat as well as electricity) cost 31.30 US$/MWh. Design limits for pipes at 100 Pa/m. The results can be seen from Figure 5.5.

When comparing steel pipe and plastic pipe systems, it is important to know, that usually steel pipes standard dimensions (DN) is related to the inner diameter, whereas the plastic pipes are designated by their outer diameter. Hence comparing the different pipe types of the same (or proximate) DN number have usually different power capacities. However in this manual, the designation DN refers to the *inner diameter* for all types of pipes. This is not true for Figure 5.5, showing the construction costs in suburb areas. Here, plastic pipes are designated tot their outer diameter. Consequently it can be seen that cost break-even is for plastic pipes dimensions DN 90 and steel pipe dimension DN 65, corresponding to a pipe-system power of ca. 500 kW.

5.3 Comparison of systems with plastic and steel pipes

There is a drawback by limiting the comparison to different pipe systems. Depending on the application, the type of the primary heat production and the type of load, the optimal use of different pipe systems will also lead to different solutions for as well the connection to the production unit as to the consumers. Hence a cost comparison may not be limited only to the pipes but should include the total system.

In the above mentioned report [32] the system costs for a certain application were also investigated. A group of 40 houses was supposed to be supplied by a biomass boiler via a steel pipe system or alternatively a plastic pipe system based on GRUDIS technique (see Chapter 4), Figure 5.6.

Heating density and other characteristic figures for this comparison is shown in Table 5.1.

Types of pipe system:

A) *Steel pipes:* Conventional single pipes, PU insulation, series II. Installation in streets, service pipes at right angles to houses.

B) Plastic pipes: Twin pipes up to DN 40 and single pipes for larger dimensions. House to house pipes with house connections installed in a supply box inside the houses.

B) Plastic pipes: Secondary connection. One substation for making the total load of all the area. House stations include one heat exchanger for radiator heating, direct connection of hot water (see Figure 4.4). 90/70-60°C system. (Alternatively direct connection of the radiator circuits and heat exchanging to the hot water preparation will imply about the same system costs).

Table 5.1: Design figures for the 3 different test areas.

Type of exploration	Exploration Area	Number of dwellings	Area of dwelling	Specific exploration	Design heating power	Total system power	No of houses	Connect. power
	m^2		m^2	m^2 (dwell)/ m^2 (area)	W/m^2	kW		kW/house
Detached houses	100 000	80	150	0.12	50	700	80	8.75
Row - houses	100 000	160	150	0.24	50	1400	80	17.5
Multi family buildings	100 000	480	100	0.48	50	2700	40	67.5

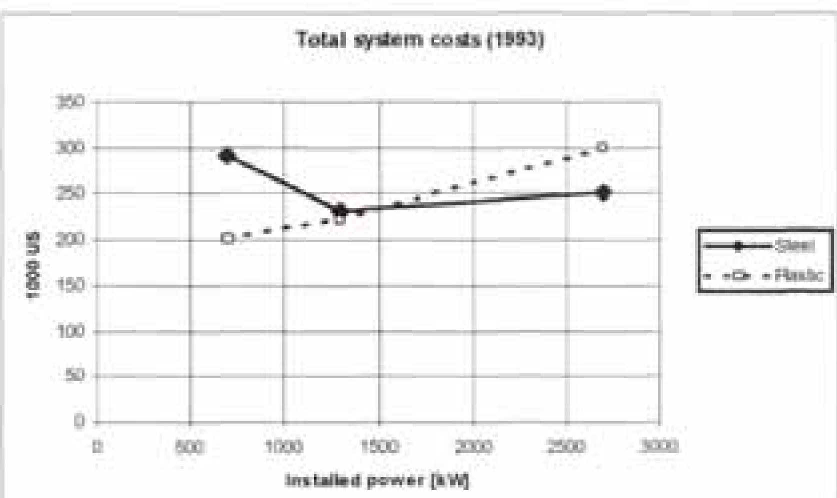


Figure 5.7: System comparison steel pipes plastic pipes (GRUDIS 1993).

Figure 5.7 shows the total system costs including pipe installation, substation for plastic pipe system and consumer stations.

A comparison of the results from Figure 5.6 and 5.7 implies that the plastic pipe system solutions inherently lead to lower costs even for relatively large systems. Whereas based on the pipe costs alone the plastic pipe systems might be limited to a power of about 500 kW, an analysis of system costs shows a break-even limit of about 1500 kW for that special application. One of the main reasons is that the plastic pipe network is operated with a number of parallel branches favouring the use of small pipes, whereas the steel pipe system is laid conventionally with a main ring system through the area. It also gets evident that plastic pipes are more favourable in low heat density study areas, whereas in areas with multifamily buildings the advantage for the larger steel pipe systems persists.

System connection:

A) *Steel pipes: Primary system connection.* One consumer station with two heat exchangers for hot water and radiator heating system respectively per house. 90/70-60°C system.

5.4 Comparison of plastic pipes with other flexible pipes

In a recent study, a broader analysis of cost comparisons of different system types have been performed in Sweden in the course of a project dealing with the connection of existing electrically heated houses to district heating. The work is described in [36] and [37]. The project is described more in detail in Appendix C1, see especially Figure C1. The task was similar to the comparison study performed 1990 [32] and described above, with the difference that the system has been really built.

44 detached, but tightly spaced houses are connected via a secondary network to primary district heating. The total load was about 600 kW. The secondary network was dimensioned to 80/65 - 40°C. One part of the study has been carried out 1996, the second part, including the investigation of alternative systems, 1998, but price-adjusted to 1996.

Whereas the first study [36] was devoted to find an optimal plastic pipe solution, the second study [37] dealt with comparison of alternative solutions including as well modern steel pipe techniques (steel twin and steel-flex) as well as plastic pipes four-pipe systems (Ecoflex-Quattro). In all cases, small-trench techniques and increased use of refill material and installation without preheating was applied. Plastic pipes were installed with house to house connections (through the gardens), whereas steel pipes were connected in the streets with service connection as straight as possible to the houses, but without having to cut off each 12 m pipe sections. The service pipes were connected by drill-on techniques. The different alternatives implied also different solutions for the consumer connections. A summary of the systems investigated and the total costs can be seen in Table 5.2.

Table 5.2: System solutions for the system alternatives of Munksundet, Sweden.

				Cost 1000 US$	Cost 1000 US$	Cost 1000 US$	Cost 1000 US$
Pipe type	System temperature	Radiator system	DHW	Substation	Pipe system	Consumer station	Other
Plastic Twin house to house; 3 pipe sections 1190 m	80/65-40	10 kW/house Steel rad. 60/40	0.35 l/s per house with press. valve (Redan)	27.6	106.5	93.5	8.1
Plastic Twin house to house; 3 pipe sections 1190 m	80/65-40	8 kW/house Steel rad. 80/40; smaller radiators (-187.5 US$/ house)	0.26 l/s per house with 200 l accumulator	27.6	93.9	96.6	8.1
PEX Quattro trench length 1028, 1154 m pipe	80/65-40	Direct connection with thermostat valves and difference press. control	Direct	29.9	127.8	47.3	8.1
Steel-Twin (main) and steelflex (service); 889 m trench 1417 m pipes	Primary system 100/70-43	60/40: connection with consumer station	Connection with consumer station	0	123.4	116	8.1

Total cost summary:	1000 US$
PEX-Twin:	235.8
PEX-Twin (accumulator):	226.5*)
PEX-Quattro:	213
Steel-Twin/steelflex	256.5 *)

*) Both systems allow the use of higher radiator temperatures and therefore smaller radiators. Using radiators with 80°C instead of 60°C dimensioning temperature will give a reduction of radiator costs of US$ 187.5 per house or totally US$ 8250 discount for the system costs.

The results show that smaller plastic pipe systems can with advantage also be built as a four-pipe distribution system with radiator water and domestic hot water distributed in two separate pipe systems, altogether combined in a single flexible jacket pipe. The maximum size for Quattro systems is DN 32 allowing the distribution of about 100 kW per pipe feed.

The study shows also, however, that steel pipe manufacturers are catching up with smaller flexible pipes and twin steel pipes, which in combination with new cold installation techniques (no preheating of pipes when buried) and refilling of excavated material can lead to low system costs similar to plastic pipes.

6 Further development

Pipes and components

Although the general trend of heat distribution systems is towards lower system temperatures and also lower pressures, the limitations of the principal operational parameters are considered to be a serious hinder for a wider use of plastic pipe systems. Manufacturers are therefore working with development of new plastic pipes systems with the aim of relieving these limitations.

One possible way is to achieve sandwich constructions with plastic pipes inside of metallic outer pipes, which can take up higher pressures. PEX pipes with aluminium jackets and an outer PE safety layer are available on the market, but mainly for the use in cold and hot water pipes at diameters up to DN 40. These pipes can be delivered for a pressure up to 1 MPa. Furthermore, these pipes can also be delivered with integrated compound insulation. Such pipes are still restricted to operation temperatures of 90°C. For use at higher temperatures, flexible metallic pipes such as steel-flex pipes, copper pipes and flexible corrugated stainless steel pipes are on the market.

A further development is directed towards the use of polypropylene (PP) for hot water distribution. Although these pipes are marketed for hot water distribution, their maximum operation temperature is lower than that of PEX and PB and therefore its use is limited to special applications. The advantage of these pipes is that they can be joined by welding, however, they are not as flexible as PEX or PB. Development work is reported in [31] in which a compound of PP and insulating PU-foam has been found to strengthen the pipe wall. It has been shown that a stress up-taking outer pipe wall counteracts the time depending weakening process of the inner plastic pipes and hence increases the service life time of the pipe for a given temperature. Because this behaviour is principally applicable on all types of plastic pipes, further development with compound structures with the aim of increasing service lifetime and service temperature can be expected.

Another problem of plastic pipes is the water vapour permeability of the medium pipe. As described in chapter 9, water vapour can more or less accumulate in the insulation, depending of the properties of the outer jacket pipe. It can be expected that further development will deal with this problem and the permeability of the outer pipe jacket will be tailored in order to achieve a controlled humidity balance in the insulation.

One question concerns the metallic fittings from the point of view of utilities. Although the market for plastic medium pipes is constrained to a few makes, many different types of fitting are available. A more uniform fitting system for all makes would in the future facilitate the efforts for maintenance and spare parts of net users. Therefore development work towards component uniformity is strongly recommended.

Laying techniques

In new-development areas, combined installation of all piped systems is desirable. By planning and constructing all supply systems such as water, gas and/or electricity, telecommunication, heat and sewage at the same time and in the same ducts, a further cost reduction for the costs of the heating part can be expected. In smaller systems, twin and also quadruple pipe system will further improve the heat distribution concept.

A new technique for quenching dead end of plastic pipes is under investigation. If this technique can be proven to be reliable for hot water pipes quenching would allow a simple method for repairing pipe sections or connecting further consumers.

Branches and Tees are still a relatively costly element in the network construction. In smaller systems it has been shown that house-to-house connections of the main system are economically more favourable than the conventional main and service techniques with larger main and smaller service pipes. However, in larger systems and under many circumstances, for example if not all houses are to be connected to the distribution systems, the conventional tree network technique must be applied. For such cases a bore-connection technique has been developed for steel pipes. For weldable plastic pipes such techniques might also be feasible. Development work is also under way for PEX pipes, where it is thought that the memory effect of this material can be used for achieving a tight connection between PEX-main and PEX service pipe.

System applications

Heat distribution techniques are influenced by heat distribution density, but also by tradition and by a reliability philosophy. In areas with high heat density, large dimensions and high supply temperature steel pipes will also in the future be the dominant choice for the pipe system. However, in places with smaller heat loads such as in urban peripheral areas or in new exploration of group of houses, flexible plastic pipe systems at lower distribution temperatures should show some advantage. The widespread use of plastic pipes in Denmark, where about 50 % of all heat distribution pipes are based on plastic pipes, can serve as an example.

In modern building standards, heat losses will be reduced and utilities are working on reducing the maximum system temperature. Small networks can very often be managed towards reduced supply temperatures and pressures to fit plastic pipes. Denmark can be mentioned as an example, where only the district heating net of Copenhagen works at temperatures, which are not suitable for plastic pipes. In most other nets, plastic pipes are used together with steel pipes, wherever these pipes suit the heat load.

Plastic pipes are also of interest in such areas where they can be connected as secondary networks via heat exchangers or pressure transformers to the district heating main. Other applications are the construction of small nets for about 50 – 100 dwellings to be heated by local renewable energy sources such as solar heating or biomass heating plants. In these applications, plastic pipe systems with its feature of literally "flexible" solutions are expected to make an important contribution to the use of renewable energy.

7 Overall Conclusions and Recommendations

(Recommendations in shadowed area)

Plastic pipe systems are today recognised as a reliable technique for a new class of heat distribution systems often referred to as ***low temperature/low pressure systems.*** In the following, some general conclusion for plastic pipe systems will be summarised. Recommendations are marked with shadowed areas.

The pipe-system

- Only cross-linked polyethylene (PEX) and to some extent polybuthylene (PB) pipe systems are so commonly in use on the market that they have been included in this handbook.
- **Both types of materials experience limitations so far as the maximum temperature and the maximum pressure for reliable use with acceptable lifetime are concerned. The nominal design pressure is 0.6 MPa. The recommended temperature limits differ slightly from country to country according to different practices of choosing safety factors. However, a continuous use at 80°C and a short-term use at 90°C are regarded as safe temperature limits in this context.**
- Plastic pipe systems are available with medium pipe dimensions between 16 mm and 90 mm inner diameters. The real system advantage compared to steel pipe systems is obvious only in the smaller diameter range.
- For small dimensions, twin pipe and quadruple pipe systems are available for some makes.
- Commonly, PEX pipes are provided with an oxygen diffusion barrier based on EVOH reducing the oxygen diffusion to insignificant values. EVOH barriers are also available on PB pipes.
- Flexible or hard PU in most systems is used as the insulation, in one product flexible PEX foam is used
- The outer jacket is in the most cases made by LDPE. In the future more emphasis will be placed on the construction of the jacket in order to optimise the vapour transport of the pipe system.
- The flexible and bendable pipe systems can be supplied coiled on drums or in bundles of several 100 meters for the smallest diameters and usually some 50 meters for the largest dimensions. Very often, they can be ordered in adequate lengths according to the specification of the designer.
- **Most manufacturers recommend today the use of easy-to-install press-fittings for joining PEX medium pipes. PB pipes can be joined by welding.**
- Humidity indication systems are usually not installed.

Laying practice

- The plastic pipe system can be easily installed by the contractor doing the groundwork. That means that instead of 3 contractors (groundwork, pipes and insulation) only one contractor needs to be engaged.
- Plastic pipe systems can be installed in relatively narrow and shallow trenches, needing not more than *10 cm* trench space beside, between and below the pipes.
- **The sand bed filling can be kept at a minimum with in the most cases 10 cm beside, between and below the pipes and 20 cm above the pipes. For the remaining trench space refill material can be used.**
- **Warning nets or strips should be laid over the sand bed.**
- **The total fill height above the pipe should be 40 cm for areas without traffic, 50 cm for areas with light traffic and 60 cm for areas with heavy traffic.**
- Most of the joints between plastic pipe systems can be completed outside the trench.
- The flexible pipes are easy to lay in house-to-house connections or in service connections between plastic pipe or steel jacket pipe main and the house station.

- The digging can be made by small chain excavators (for large lengths) or mini-excavators avoiding obstacles such as bushes, trees, stones etc.

- Because of the large thermal expansion coefficient of the plastic material it is necessary to provide anchoring of the plastic medium pipes to the house or to the foundation if connecting them in right angle to the in-house pipe connections made of copper or steel. Axial forces can usually be taken up by the pipe system.

- Plastic pipes can be inserted underground for example through gardens or under roads by using horizontal drilling processes such as earth hammer or hydraulic boring.

- Laying during cold winter times can be facilitated by preparing the pipes indoors and blowing warm air through the pipes during the installation procedure.

System technique

- Plastic pipe systems can be connected to conventional district heating main systems via heat exchangers or pressure transformers. In either case the maximum pressure and temperature requirements must be observed.

- If the main system operates at temperatures and pressures adequate for plastic pipes, plastic pipe systems can also be connected directly to the main district heating system.

- Direct connection either to the house radiator system or - by means of the GRUDIS connection - to the tap water system avoids temperature degradation and allows lower supply temperatures.

- Plastic pipe systems with oxygen barriers can be directly connected with steel pipes and or steel radiator systems. To avoid corrosion problems safely during the system lifetime, it is recommended in Germany that the amount of steel surfaces is 30 % or more of that of plastic pipe surfaces. However, in Scandinavia it is considered that 10% steel surfaces are sufficient for save operation of mixed pipe systems, the difference lying in the judgement of risks for pitting corrosion in steel pipes.

Operation

- Plastic pipe systems should be operated with ambient temperature depending supply temperatures accordingly, which reduces the amount of the highest temperatures (90°C) to a few 100 hours a year.

- Higher operation pressures and temperatures than nominal temperatures must be avoided by safety valves and temperature limiters.

- Continuous filtering of the district-heating medium is recommended for the reason of initial operation and corrosion control.

- Water treatment methods usual for district heating are in general also applicable to plastic pipe systems.

Economy

- Combined installation with other conducting systems such as city water, gas or electricity can reduce the installation costs attributable to district heating.

- The system economy of plastic pipe systems in comparison with steel pipe systems depends by and large on local circumstances such as system type, supply temperature, heat density of the load and local pricing tradition. In some countries a clear cost advantage for small systems up to an inner diameter of 63 mm has been proven, in other countries the price difference at steel pipes has been found to be marginal. Generally speaking, it can be stated that the economical advantage should be most expressed for small dimensions. For instance in Sweden and Denmark, cost advantages are foundfor systems up to 500 kW per pipe stem.

- If cost advantages for plastic pipe systems can be found in comparison with steel pipe systems, they are primary due to lower installation and groundwork costs. Material costs for the pipes themselves are rather higher than that of steel pipes.

Section B

MATERIAL ASPECTS

8 Pipe Materials

For many reasons, economical, environmental as well as technical, plastic pipes have during the last decades developed as being the market leader for cold water distribution. Another important application is low pressure natural gas distribution. For hot water applications, the use of plastic pipes is relatively recent. The reason is the mismatch of traditional construction principles of for example district heating pipes and the operating limitations for plastic pipes. In order to understand these limitations, we have to summarize shortly some fundamentals on plastics and polymers.

8.1 Plastic as a material

Plastics are basically made of the hydrocarbons found in crude oil. Dominant hydrocarbon groups are paraffins, naphtenes and aromatics. These groups might consist of either long-chained and/or branched molecules or cyclic molecules. Carbon atoms can be bounded to hydrogen atoms or to other carbon atoms, making the number of possible molecules practically infinite. The more C-atoms, the higher the boiling point of the substance. This fact is used for separating the various substances contained in crude oil by destilling it in a fractionating column, with the light, low boiling point products in the top and the heavy oils leaving the column in the bottom.

In order to make plastics out of the fractionated products, a further refinement of the distillates is necessary. During these refinement processes, two main plastic groups can be produced: *Thermoplastics and Thermosetting plastics*. The pipe materials considered in this handbook all belong to Thermoplastics.

8.1.1 The production of plastics

Thermoplastics

Thermoplastics are characterized by the fact that their molecules do not take up a completely static position in relationship to each other. They become liquids if they are heated up to their melting points and hence are then "plastic" or moldable. To this group belong polyamids, polyethylenes, polypropylenes, polystyrenes, polybuthylenes and polyvinyl chlorides. A common notation for these substances is polyolefins.

Thermosetting plastics

The molecule chains in thermosetting plastics are so incapable of changing their mutual positions that once they have been given a desired form, they cannot be reorganized through heating. Among these plastics are the amino plastics, epoxy resins, and phenolic resins.

8.1.2 Polymers and plastics

Most of the plastics used for pipe manufacturing are formed by polymerization out of monomers. Polymerization means that similar atomic building groups are linked together by means of chemical treatment involving high pressure and temperature, solvents and catalysts. For example, the monomer hydrocarbon ethylene can be processed to form polyethylene (see Figure 8.1). Polymers are the main ingredients in plastics. However, in order to give plastics suitable properties, some additives such as stabilizers, cross-linking agents, colors, and so on might be supplied as well.

Polyethylene (PE)

The monomer hydrocarbon ethylene can be processed either by treatment at high pressures and high temperatures to form the polymer "low density polyethylene" (LDPE, density 0.91 - 0.94 Mg/m³, melting point 105 -125°C) or by treatment at lower temperatures and lower pressure in a solvent and in combination with catalyzing agents in order to form "high density polyethylene" (HDPE, density 0.94-0.97 Mg/m³, melting point 115 - 145°C). Thousands of CH2 groups might contribute to form a polyethylene chain (1 molecule). The higher the degree of crystallinity, the higher the density of the material and the greater the strength of the plastic. On the contrary, material with too high degree of crystallinity is usually very brittle. The raw material for PEX should therefore have an optimal amount of crystallinity of about 90 %.

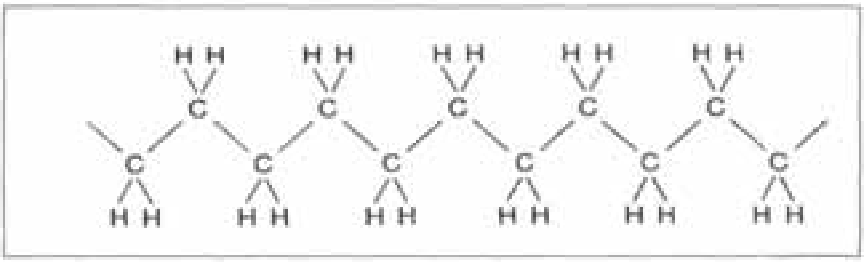
Figure 8.1: Structure formula for ethylene, polyethylene and a molecular model for PE. (Source Wirsbo, [20]).

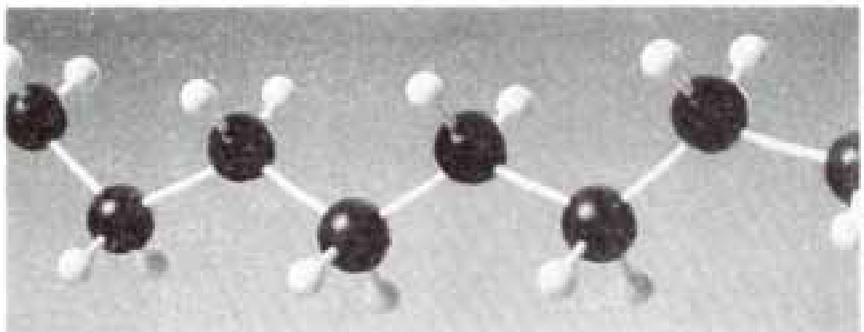
Monomer (ethylene):

$CH_2 = CH_2$

Polymer (polyethylene):

$(-CH_2\ -CH_2\ -CH_2\ -........)_n$





Polybuthylene (PB)

Polybuthylene is a thermoplastic that is produced through the Ziegler - Natta - polymerization from 1-buthylene. Below melting point at about 125 - 130°C, it is highly crystalline, and melts into a low crystalline, unstable material which reverse back to the crystalline state after cooling. Polybuthylene is therefore weldable. The density is about 0.91 Mg/m³.

Monomer (1 - buthylene):

$-(CH_3CH_2CH = CH_2)$

Polymer (polybuthylene):

$-(CH_2CH)_n-$, with C_2H_5 attached to CH

Polypropylene (PP):

Polypropylene is made from propylene under relativly low pressure and temperatures in the presence of catalysts according to the same method as polybuthylene. The chain molecules can weigh 40 000 - 60 000 g/mol and form a helix spiral which can be packed quasicrystalline. By this way, a crystalline amount of 50 % can be reached. The density is about 0.9 Mg/m³ and the melting point of the crystalline material 165°C. On the other hand the melting point of the amorphous part is low, about 0°C, which gives the material worse high temperature properties than PB. PP is also weldable.

Monomer (propylene):

$CH_3CH = CH_2$

Polymer (polypropylene):

$-(CH_2\ -CH)_n-$, with CH_3 attached to CH

Cross-linked polyethylene PEX

The X is the symbol for cross-linking. Polyethylene as shown in Figure 8.1 consists of layers of long molecule chains with a low degree of cross linking. Figure 8.2 shows schematically the coexistence of crystalline and amorphous arrangements of the molecules. By inter-linking these chains into a three dimensional network, the stability and strength of the polymers can be substantially improved and can be better than for the branched polyolefins PP and PB. For instance, melting and dissolution of cross-linked polyethylene is made considerably more difficult. This - on the other hand - has the result that PEX is not weldable.

For this reason, different cross-linking processes have been developed, resulting in various degrees of cross-linking and hence in differences of the properties of PEX from different manufacturers. Therefore, in the product manuals it is important also to refer to the manufacturer of the PEX-pipes and to the method used for cross-linking and the degree of cross-linking achieved.

The Thomas Engel's Process (PEX-a)

In this process, cross-linking is achieved by adding peroxide to the other raw materials such as HDPE, all in form of powder, to be processed. The powders are stirred and fed

Figure 8.2: The structural arrangement of HDPE chain molecules. (Source Wirsbo, [20]).

to the extruder under high pressure and temperature leaving the material in the amorphous state. The action of the peroxide (a substance containing – O – O – structures) is to "steal" hydrogen atoms and to mediate cross atomic bonds between carbon atoms of adjacent molecule chains. These actions take place in the complete amorphous state of the PE material during extrusion, which allows a maximum of cross-linking. This process is applied by Wirsbo and the resultant type of PEX material is called PEX-a.

Silane Cross-linking (PEX-b)

This process was developed by Dow Chemical Company and is based upon saturating the PE macromolecule with silicone. Subjecting it to water vapour in the presence of a catalyser activates the cross-linking process. The linking takes place through so-called siloxane bridges. These bridges are, however, weaker than normal bonds. Example of manufacturer of PEX-b pipes is AT Plastics Incorporation, USA.

Radiation cross-linking (PEX-c)

Cross-linking can also be achieved by electron-rays (β-radiation). This is done at room temperature, preferentially acting on the amorphous structures, not disturbing the degree of crystallinity. This process is used a. o. by Hewing GmbH Pro Aqua, Germany.

AZO method (PEX-d)

In this method, AZO compounds containing – N = N –bonds are responsible for the cross-linking. First, the pipes are formed at lower temperatures, thereafter the temperature of the molten salt bath is raised to the reaction temperature of the AZO compound. Also in this process, a relatively high process temperature is involved.

PAM (Pont-à-Mousson) method

The cross-linking is performed at the high reaction temperature of the peroxide used in the process (around 250°C) in a molten-salt bath. However, at these temperatures it can be difficult to control dimensions and shape of the pipes with high accuracy.

UHF cross-linking

Polarized peroxides can selectively absorb Ultra High Frequency radiation and hence disintegrate selectively into radicals which mediate cross-linking. This can be done at temperatures below the normal reaction temperature of peroxides. The PE chains themselves are not polarized and therefore will not absorb UHF energy.

It is also possible to add other polarized substances such as carbon black and to use unpolarized peroxides which will form radicals through thermal decomposition. The material is then extruded at as low a temperature as possible and afterwards treated by UHF radiation. This method results in a very homogenous cross-linking effect.

8.2 Some important properties of polyolefins

8.2.1 Long-term stability

Oxidation is the main life-time limiting factor also in plastic pipes as it is in metal pipes. A common testing method for plastic pipes is time to failure measurements based on internal-pressure tests at different temperatures. Typical for all the investigated polyolefins is a declining logarithmic time curve for the Hoop stress causing pipe rupture, according to Figure 8.3. In general, this is a very strong function of the long-term operating temperature.

The different phases with different inclinations correspond to different processes in the polyolefins. Phase I is mostly due to mechanical stresses on the molecular bonds. Beginning with Phase II, oxidation processes are destroying the internal bonds of the molecular chains down into ever smaller pieces. Finally, the material weakens and

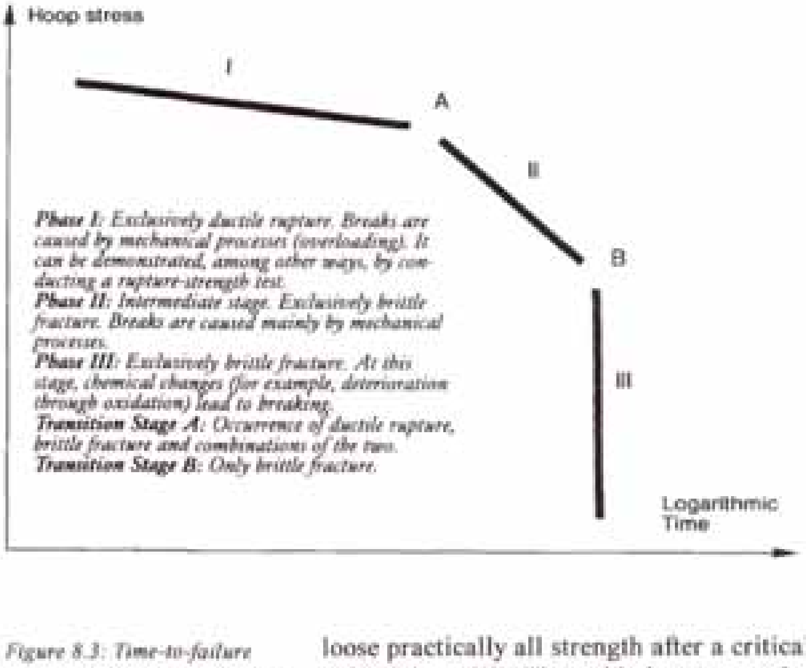


Figure 8.3: Time-to-failure graph - schematically. (Source Wirsbo [20]).

loose practically all strength after a critical point (Phase III). The oxidation process is facilitated by internal branches as it is the case in PP and PB. UV-light has the same weakening effect.

8.2.2 Influence of degree of cross-linking for PEX

The amount of cross-linking is an important factor in PEX. It is usually described in % of the maximum possible links.

Increased cross-linking results in:
- longer time to failure (increased rupture strength) and to occurrence of Phase III
- shorter Phase II
- increased resistance against the influence of unintentional defects (such as scratches).

Too high cross-linking on the other hand makes the PEX material brittle and decreases again the time to Phase III. The best or optimal degree of cross-linking is also dependent on the cross-linking method used. Generally a degree of cross-linking of 60 - 80 % is considered to be optimal for PEX.

Stabilizing agents

Most of the plastics made of polyolefins and used for hot water pipes are treated with stabilizers in order to counteract the oxidation process. The action of the stabilizer is to attach to the radicals that form when bonds are breaking up due to the oxidation process. These radicals, if free, would induce new bond-breaking processes and hence accelerate the deterioration of the material. Hence the action of the stabilization agent is mostly to increase the time for occurring of Phase III.

8.2.3 Elasticity and creep

All plastic materials as well as most other materials respond with deformation to the application of a constant load. The amount of deformation for a certain load is strongly depending on the operating temperature. As long as the deformation is reversible when the load σ is removed, we talk about elasticity. Elasticity is an important property for flexible pipes and is described by the modulus of Elasticity E:

$$E = \frac{\sigma}{\varepsilon} \quad [N/mm^2 = MPa]$$

with:

$$\varepsilon = \frac{\Delta L}{l} / \Delta T, \text{ elongation } [\%]$$

The lower E, the more flexible and bendable is the material.

However, above a certain load, the deformation is non-reversibly increasing in time. Depending of the amount of load, the material will sooner or later surpass the point where creeping accelerates and finally ends in a rupture. This is the process,which governs the lifetime of plastic pipes in Phase I and Phase II of the time-to-failure graphs (see Figure 8.3).

The point with the maximum applicable force gives the tensile strength σ_b of the material.

Change in length

Plastic pipes exhibit the peculiarity of both increasing or shorting their length, much more than metallic pipes. The usual process for it is thermal expansion described by the linear expansion coefficient a according to the equation:

$$a = \frac{\Delta L}{L} / \Delta T \quad [K^{-1}]$$

As for all plastics, this coefficient a is about ten times higher in plastic pipes than for steel pipes and results in a remarkable change of length of heated plastic pipes. These changes must be accounted for if piping systems are planned or maintained. For flexible pipes this is no problem in general because the pipes can take up length changes in bows and all the small sinous curves they are laid down with, but when disconnecting pipes under maintenance services, one has to be prepared that a cold pipe under stress might contract.

Another phenomena resulting also in length changes, general radial shrinkage, is the memory effect occurring to some extent in all plastic pipes. The reason is that the molecular chains during the extrusion process are becoming more or less axially aligned and then are frozen in this orientation. During operation, the constant temperature and pressure load is releasing parts of these alignment, giving the molecules more random distribution and hence shrinking the pipe. The shrinkage can be as much as 0.5 %, its corresponding tensile strength is normally handled by the pipe coupling. However, when taking apart this coupling, for example during a repair work, the pipe can disappear in a feed tube and will be difficult to reconnect.

Typical values of technical parameters of plastic pipe materials are given in Table 8.1.

Table 8.1: Physical parameters of plastic pipe materials.

Values at room temperature	Unit	PEX	PB	PP
Degree of cross-linking	%	>75		
Density	kg/m³	940	920	900
Tensile strength σ_b	MPa	13,7	17	33
Modulus of elasticity E	MPa	500	400	1300
Elongation at break	%	>300	320	800
Coeff. of linear therm. expansion a	K^{-1}	1.4×10^{-4}	1.3×10^{-4}	1.0×10^{-4}
Thermal conductivity λ	W/(K·m)	0.4	0.22	0.14

8.3 The service lifetime of hot water pipes

8.3.1 Long-term testing

Each district heating network will be designed for a certain lifetime. For example, the "Regulations for testing of plastic pipes" of the Swedish District Heating Association (FVF) state that "the manufacturer has to show that the pipes exhibit a minimum life time of 30 years at 80°C and 0,6 MPa ". Hence the determination of the life time is one of the most important testing moments.

The most established way to do this is to install a large number of well defined and well calibrated pieces of pipes in hot chambers kept on different, well controlled temperatures. The pipes are loaded with water at different internal pressures in order to achieve different Hoop stresses. The outer pipe environment is either water, air or a detergent for accelerating the rupture process. Figure 8.4 shows the principal equipment used by Studsvik Polymer AB for lifetime tests. The established laboratories such as this one in Studsvik have thousands of probes under test at any time.

The test stand time to rupture is monitored, depending on test conditions being hours up to a couple or even tens of years, each pipe failure giving one point on a curve. The type of rupture (ductile or brittle) gives indication about the phases involved in the failure.

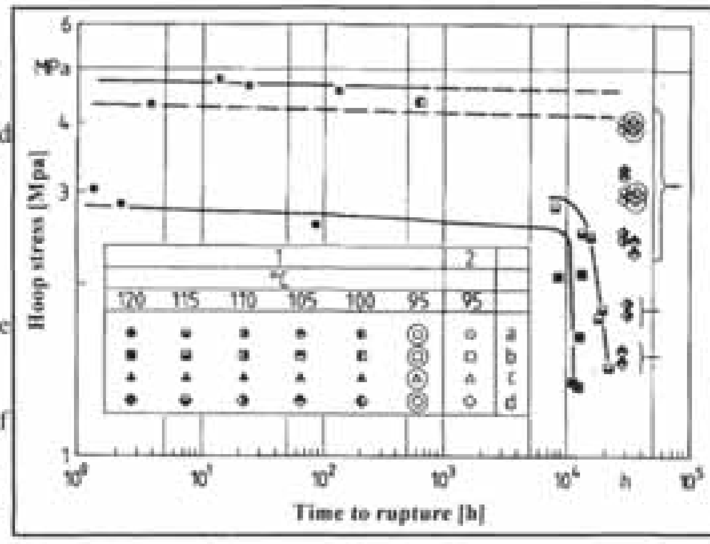


Figure 8.5: Time to failure diagram for PEX, [2].

Figure 8.5 shows an example for the time to failure properties for PEX [2]. The Hoop stress can be calculated by the simple formula:

$$\sigma_H = \frac{p \cdot (d_o - s)}{2s} \qquad [\text{MPa}]$$

with:

s = wall thickness [mm]
d_0 = outside pipe diameter [mm]
p = inside testing pressure [MPa]

It becomes also evident from the diagram in Figure 8.5. that phase II under certain circumstances can be absent or very short in well stabilized materials.

From such measurements, performed during many years in various laboratories around the world, sets of curves have been derived determining the minimum requirements for the durability of polyolefins for hot and cold water distribution, as it now is proposed in a Draft (1998) International ISO Standards are shown in Figure 8.7 a, b and c (references see Chapter 10).

The curves show the principal similarities for these three types of polyolefins. The higher the temperature, the sooner the knee indicating phase III will be reached. From these curves, a connection between life time t and temperature T (for given Hoop stress) can be determined. This connection is called ***Arrhenius' law*** and can basically be written (for a given pressure):

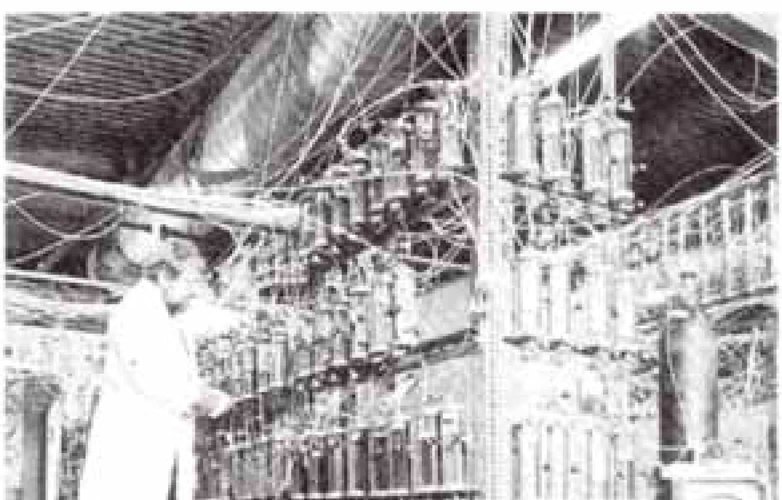


Figure 8.4: Time to failure test equipment of Studsvik Polymer AB (Source Wirsbo [20]).

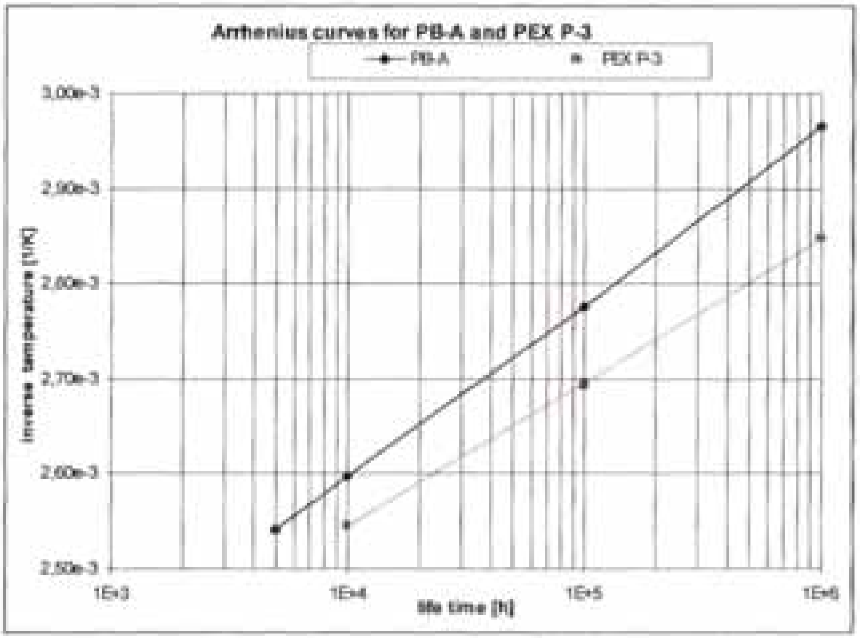


Figure 8.6: Arrhenius' plots, indicating lifetime of different plastic pipes of recommended qualities on the market.

$$\log t = A + \frac{b}{T} \qquad [h]$$

with:

T = operating temperature [K]
A, b = constants.

Figure 8.6 shows these Arrhenius curves for PB and PEX P-3 according to measurements at Studsvik [2, 3]. It should be noted that the curves are only valid for a limited temperature interval up to temperatures well below the melting points of the respective materials.

It should also be noted that the inclination of the straight line in the diagram (i. e. the factor b in the Arrhenius' law) for most of the polyolefins is between 2,5 and 3 per 10°C. This means that the acceleration factor for aging tests is about 2,5 to 3, i. e. the test time can be reduced by that factor, if the test can be carried out at 10°C higher temperature. In other words, the expected life time of a material is 2,5 - 3 times higher for each interval of 10°C for which the actual operating temperature is lower than the test temperature. However, one must be very careful in choosing the maximum test temperature because material properties can change abruptly at high temperatures due to phase change.

The Draft (1998) ISO Standards define also constants for the Arrhenius' curves as a function of Hoop stress and temperature in the sense of minimum requirements.

Table 8.2 summarizes these requirements according to the following equations for the left hand and right hand parts, respectively, of the curves shown in Figures 8.7 a, b, c.

(left part)

$$\log t = A_1 + B_1 \cdot \frac{\log \sigma}{T} + C_1 \cdot \frac{1}{T} + D_1 \cdot \log \sigma + E_1 \cdot T^7 \cdot \log \sigma$$

(right part)

$$\log t = A_2 + B_2 \cdot \frac{\log \sigma}{T} + C_2 \cdot \frac{1}{T} + D_2 \cdot \log \sigma$$

with:

t = time [h]
T = operating temperature [K]
σ = Hoop stress [MPa]

Table 8.2: Constants for set of life time curves of plastic pipe materials describing minimum requirements according to Figure 8.7 a - 8.7 c.

Material		PEX	PB	PP-R random copolymer
left part	A_1	122,134	-430,866	-55,725
	B_1	0	-12510	-9484,1
	C_1	-25046,7	173892,7	25502,2
	D_1	-12,6273	290,0569	6,39
	E_1	$-9{,}8772107 \cdot 10^{-12}$	0	0
right part	A_2	-	-129,895	19,98
	B_2	-	37262,6	0
	C_2	-	52556,48	9507
	D_2	-	88,56734	-4,11

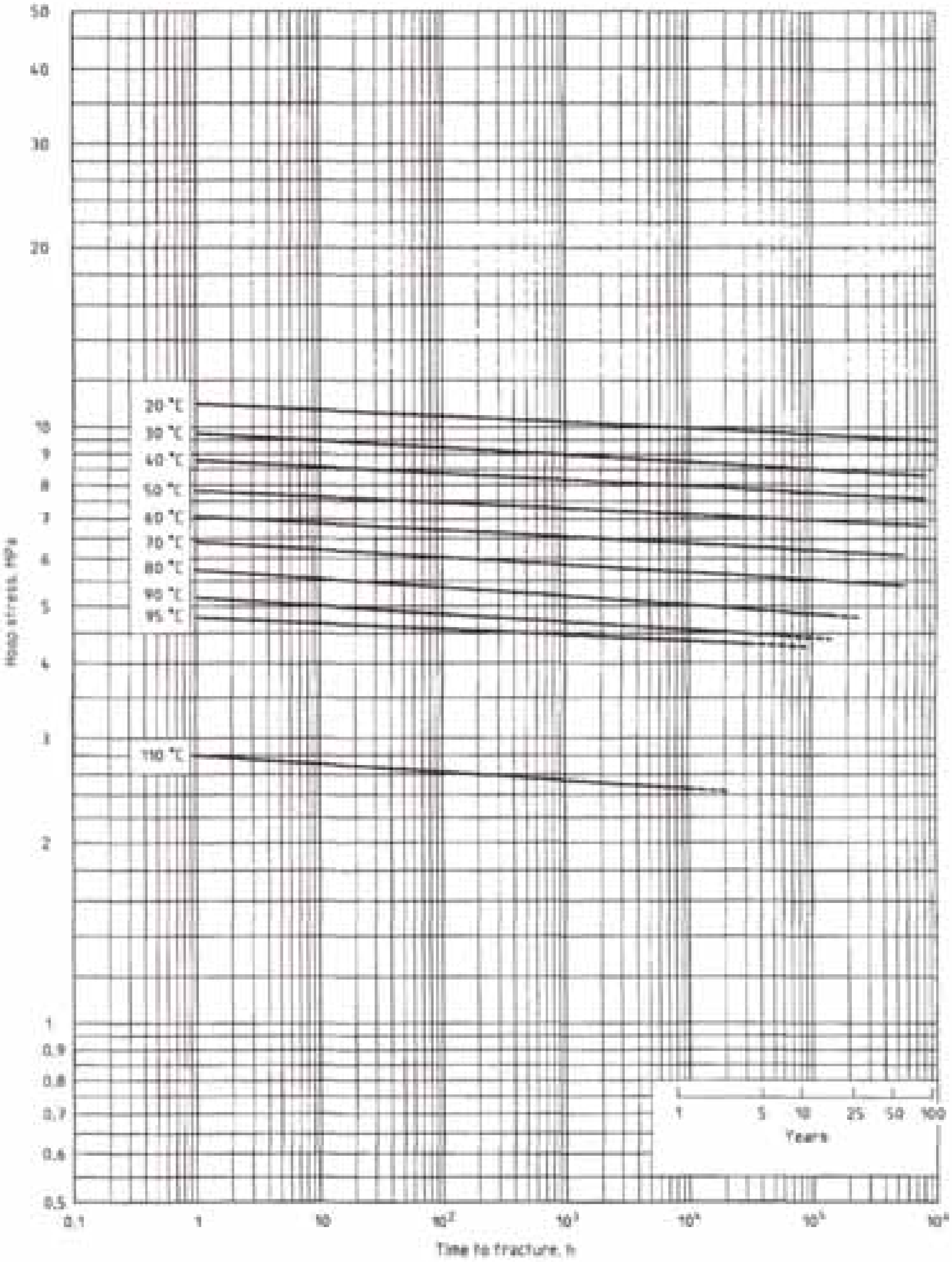


Figure 1 — Expected strength of crosslinked polyethylene (PE-X) pipes

Figure 8.7a: Time to failure diagram for PEX (reference see Appendix C4).

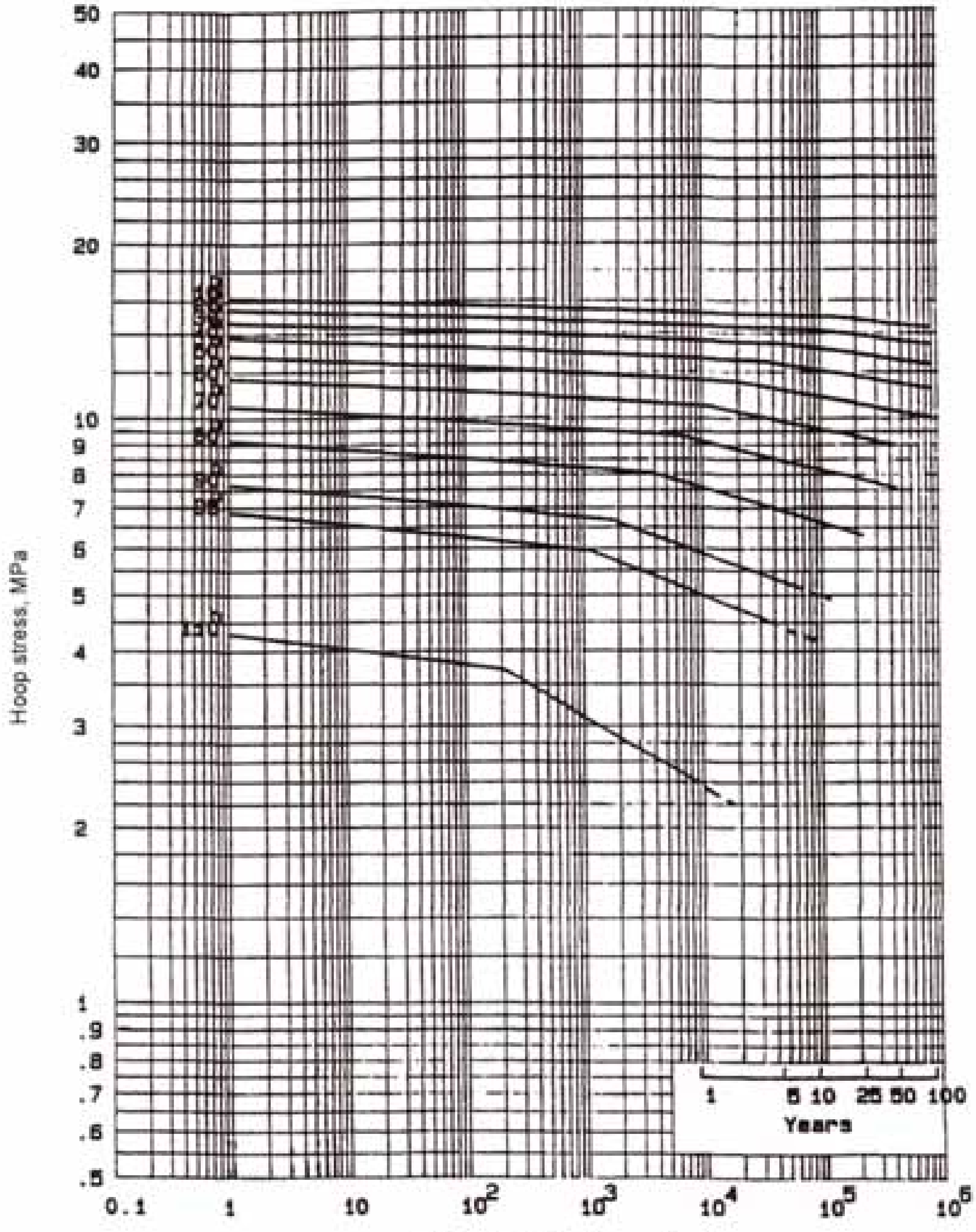


Figure 8.7b: Time to failure diagram for PB (reference see Appendix C4).

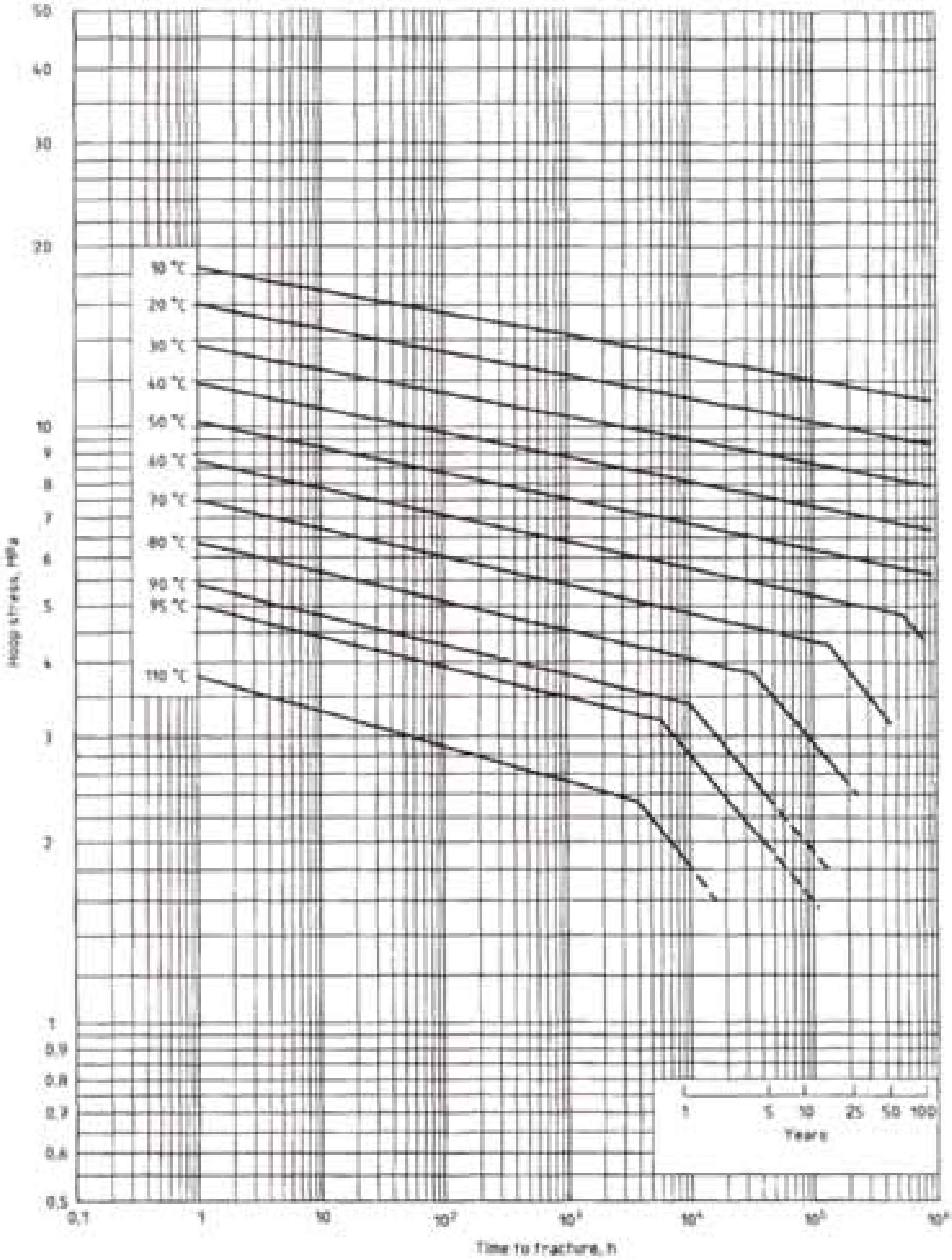


Figure 3 — Expected strength of PP random copolymer pipes

Figure 8.7c: Time to failure diagram for PP (reference see Appendix C4).

8.3.2 *The service life time*

The Arrhenius' plots according to Figure 8.6 give the lifetime for PEX and PB pipes being in service at constant temperatures all the time. E.g. PEX is expected to exhibit a service life time of ca 12 years at 90°C and Hoop stresses of 4 MPa. These Hoop stresses correspond, so far standard PEX pipes are concerned, to certain operational conditions and give some freedom to the planning engineer to define appropriate safety limits. For example in Germany, a safety factor of 1,8 is applied resulting in an operational pressure of 0.5 MPa [4]. In Scandinavia, a safety factor of 1.5 results in an internal pipe pressure of 0.6 MPa [22, 23].

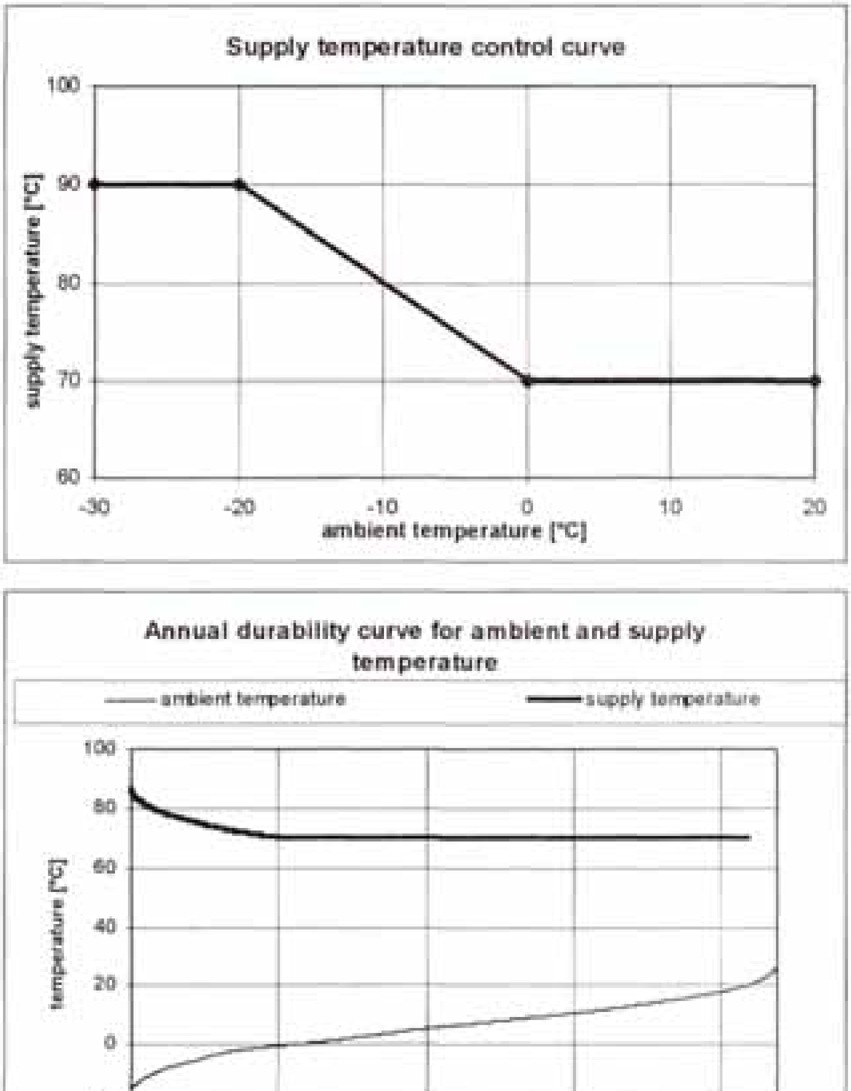


Figure 8.8: Example of the temperature control in a district heating network for plastic pipes. a) Supply temperature control curve. b) Annual durability curve for ambient and supply temperature.

However, in a real district heating network, the supply temperature will normally be controlled as a function of the ambient temperature, and only a short period will be at the maximum temperature.

As an *example*, we can assume a district heating supply temperature control according to Figure 8.8a, resulting in a temperature durability diagram according to Figure 8.8b.

The corresponding service lifetime can then be calculated according to *Miner's rule* under the assumption that the operating temperature cycle is about the same every year. The expected lifetime of the pipes can be estimated according to the following equation:

$$L = \left(\frac{t_1}{L_1} + \frac{t_2}{L_2} + \dots \frac{t_n}{L_n}\right)^{-1} \quad [h]$$

with:

L_i = expected lifetime at temperature T_i [h]
t_i = annual time fraction the system is operated at temperature T_i.

Hence, the lifetime of pipes can be calculated using the temperature durability diagram of Figure 8.8b as shown in Table 8.3. For the example of Figure 8.8, the life time averaged operating temperature will be about 73°C and the average life time of PEX pipes will be 95 years. For PB a similar calculation results in a lifetime of 40 years.

In practice, pipes for a given material can be designed with such wall thickness so that the pipes will withstand district heating temperatures up to 90°C or even 95°C with satisfying life times.

According to recently proposed standards a safety value (1,3) is proposed. According to these standards, operating times as shown in Table 8.3 can be expected.

Type	T = 70 °C	T = 80 °C	T = 90 °C	70/90 °C
PEX(s = 4.6 mm)	>50	>50	>50	>50
PB (s = 3.7 mm)	>50	>50	17	45

Table 8.3: Minimum life time (year) of plastic pipes (Ø = 50 mm) and wall thickness as at different temperatures and in a 90/70 °C, internal system pressure P = 0.6 MPa, (safety

The maximum Hoop strength values for various temperatures as a function of the time are shown in Table 8.4.

For detailed design requirements of plastic pipe systems see further in the ISO standards ISO 3213, 10146, ISO/DIS 15874-2, 15875-2, 15876-2.

Note: ! The lifetime of pipes in a network with variable supply temperatures is considerably longer than the life time would be if the net is solely operated at the maximum operating temperature.

The safety factor of the preliminary standards mentioned above for plastic pipes is 1.3. This is lower than the recommended factor in Germany (1.8) and in the Scandinavian countries (1.5).

Table 8.4: The maximum Hoop strength values for various temperatures as a function of the time.

Type	time (years)	T = 70 °C	T = 80 °C	T = 90 °C
PEX	1	5.6	5	4.5
	5	5.5	4.9	4.4
	10	5.4	4.9	(4.4)
	15			(4.4)
	18		4.8	
	25	5.4	(4.8)	
	50	5.3		
PB	1	9.0	7.6	5.0
	5	8.5	6.9	4.3
	10	8.2	6.6	
	15			
	18			
	25	7.7	6.3	
	50	7.4		
PP-R	1	4.9	4.1	3.4
	5	4.5	3.6	2.4
	10	4.4	3	(1.6)
	15		2.6	
	18			
	25	3.8	(2.4)	
	50	3.2		

8.4 Oxygen diffusion through plastic material

The diffusion of oxygen through plastic pipe materials is considered to be one of the major threats to hot water systems. In earlier times, this drawback was overcome by using metals qualified for tap water applications even in plastic pipe distribution systems [24]. Nowadays, all plastic pipes to be used in hot water distribution systems should be supplied with an integrated *diffusion barrier*.

8.4.1 Types of diffusion barriers

The most common types of diffusion barriers on PEX pipes are

- *Ethylenevinylalcohol* (under the make names EVAL (Wirsbo), EVOH or evalPEX)
- *Metal sheet* in or around the plastic pipe

Metal films have in laboratory tests been proven to be sensitive to temperature cycling with high risks of delamination shortening the lifetime. If delamination occurs, oxygen permeation can occur through the slit. Products on the market with Al-sheets are PEX-pipes from I.C.-Møller and MT-PEX pipes by Hewing GmbH, Germany.

A diffusion barrier made of *ethylenevinylalcohols* is nowadays the technique most used for oxygen barriers. We will use here the nomenclature EVOH for all makes of this type of barrier. In production, this film is normally glued on the PEX pipe after the extrusion. It is important that this EVOH film is covered with an outer protection layer of a lacquer or plastics, depending on the make, in order to protect the barrier during all handling under transport and installation.

The following properties of the EVOH oxygen permeation barrier should be noted:

- The barrier must be physically attached (glued) to the PEX pipe in order to provide a safe protecting function

- A well functioning barrier increases the life time of the PEX pipe because of reduced oxidation
- The diffusion barrier has to be protected against outer damages such as scratches.

8.4.2 Diffusion rates in PEX

The following relation describes the diffusion process in plastic pipes *without a diffusion barrier*

$$F_p = D\frac{(p_o - p_i)\cdot 2p\cdot L}{\ln\frac{d_e}{d_i}} \qquad [g/s]$$

with:

F_p = oxygen flow through pipe wall [g/s]
D = coefficient of diffusion for oxygen through PEX material [g m/(m² bar s)]
p_i = inner partial pressure of oxygen [bar]
p_o = outer partial pressure of oxygen [bar] (1bar = 0.1 MPa)
d_o = outer wall diameter [m]
d_i = inner wall diameter [m]
L = length of pipe [m].

The diffusion coefficient D is a material constant and in general depending on the temperature. The oxygen flow rate is ***inversely proportional*** *to the wall thickness and* ***directly proportional*** *to the difference in oxygen partial pressure inside and outside the wall and of course proportional to the length and the diameter of the pipe.*

By means of the constant D, the increase of the oxygen concentration as a function of time in the water flowing in a closed system with a permeable pipe of the length L can be calculated:

$$C_t = C_o\left[1 - \exp\left(-\frac{D\cdot t\cdot p_o\cdot 2\cdot \pi\cdot L}{C_o\cdot V\cdot \ln\frac{d_a}{d_i}}\right)\right] [g/m^3]$$

with:

C_t = concentration at time t [g/m³]
C_0 = initial concentration at time 0 [g/m³]
V = volume of pipe system [m³].

In pipes with a diffusion barrier, the barrier is in general much thinner than the wall thickness of the pipes. In the case of PEX in practice, a thin EVOH film is glued on the PEX pipe, see figure 8.9. The thickness of the diffusion barrier is the same on all plastic pipes. The absolute value of the permeability of this barrier is orders of magnitude lower than that of the plastic pipe material.

Therefore the coefficient of permeability P_b for oxygen in pipes ***with barriers*** *is in first approximation* ***independent of the wall thickness****. The oxygen flow increases proportionally to the difference in oxygen partial pressure inside and outside the wall and with the diameter of the pipe.*

P_b = coefficient of permeability for oxygen in plastic pipes with oxygen barrier [g /(m² bar s)]

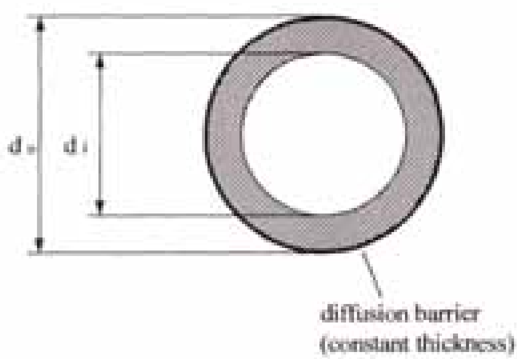


Figure 8.9: Plastic pipe with diffusion barrier.

Diffusion rates for PEX pipes with and without diffusion barriers have been measured in different laboratories, [4, 11, 25, 26] .

As an example, Figure 8.10 shows results of the diffusion stream D_t measured in Germany by the Staatliche Materialprüfungsamt Nordrhein-Westfalen. It gets evident from the diagram that the function of EVOH barriers are strongly temperature dependent. It should be noted that also the product using an Al-sheet as diffusion barrier exhibits a considerable diffusion stream, which on the other hand is independent of temperature.

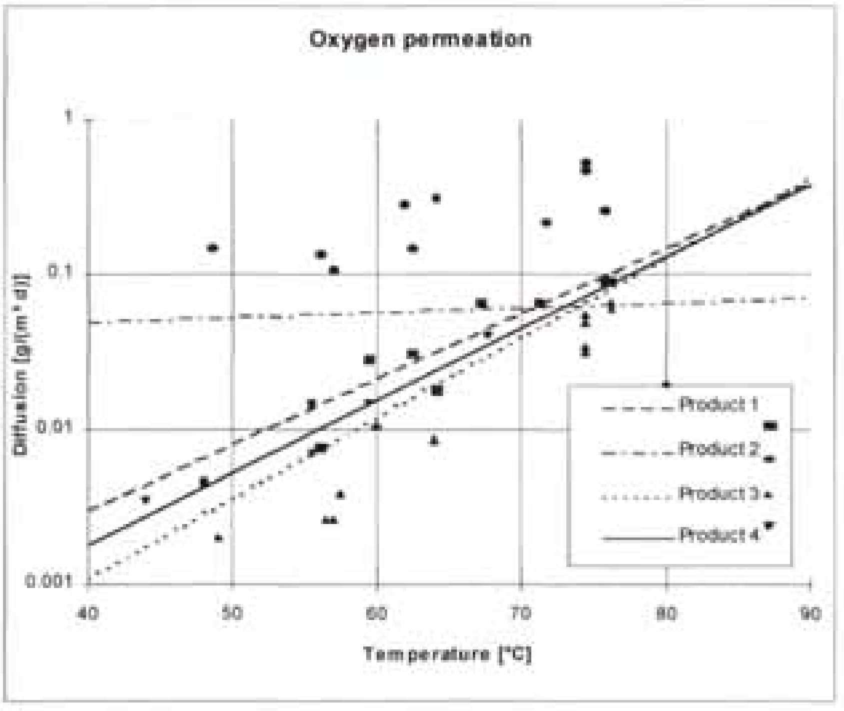


Figure 8.10: Oxygen permeation through plastic pipes in four pipe systems. Product 2 has an Al-sheet barrier, the other systems use EVOH barriers.

The results from such measurements can be used for calculating the coefficient of permeability for pipes with oxygen permeation barriers according to:

$$P_c = 1{,}38 \cdot 10^{-11} \cdot D_s \cdot d_i \,/\, \Delta P \quad [\mathrm{g/(m^2 \cdot s \cdot bar)}]$$

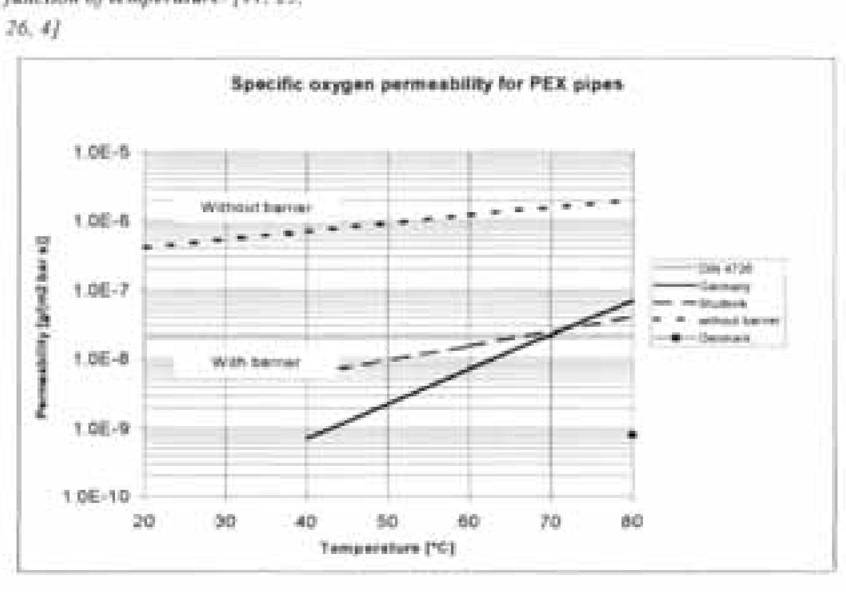
with

D_s = diffusion stream (g (oxygen) per m² and day)

di = inner pipe diameter (m)

ΔP = actual partial pressure difference for oxygen (0.21 bar).

Figure 8.11: Oxygen permeability for PEX pipes with and without diffusion barrier as function of temperature. [11, 25, 26, 4]



Some results for the coefficient of permeability in PEX pipes derived from measurements in different countries are summarized in Figure 8.11.

The measurements are made on pipes with dimension 32 x 2,9 mm. It is shown that the EVOH barrier reduces the oxygen permeability between a factor 30 and 1000, depending on the temperature. It is also shown a large spread of measured values depending on different makes and qualities. The notation DIN 4726 refers to the standard for floor heating pipes. The reason for the remarkably low value measured in Denmark is not known. It can reflect the influence of the protection of the total pipe system (oxygen barrier, insulation, jacket) on the oxygen diffusion, however, this conclusion is not supported by the German results.

Polybuthylene pipes

In principle the diffusion problems are similar for polybuthylene as for PEX pipes. On the market protected and unprotected pipes are found. PipeLife produces pipes with a PB-Al-PB laminate. Nowadays also pipes with EVOH permeation barrier are on the market. Results about the oxygen permeation in these pipes are not known but the diffusion properties should be similar to those of PEX pipes.

8.5 Diffusion of water vapour through medium pipes

The influence of the diffusion of water vapour through the wall of PEX medium pipes on the pipe system is under investigation in Germany [4, 27]. In pipe systems consisting of media pipe, insulation and jacket, accumulation of moisture in the insulation of the pipe-system or also on the innerwall of the jacket can be expected, if the permeability of the jacket is less than that of the medium pipe. Moisture which accumulates in the insulation is expected to reduce the thermal resistance of the insulation. This on the other side will increase the temperature of the jacket and hence increase its permeability until equilibrium will be

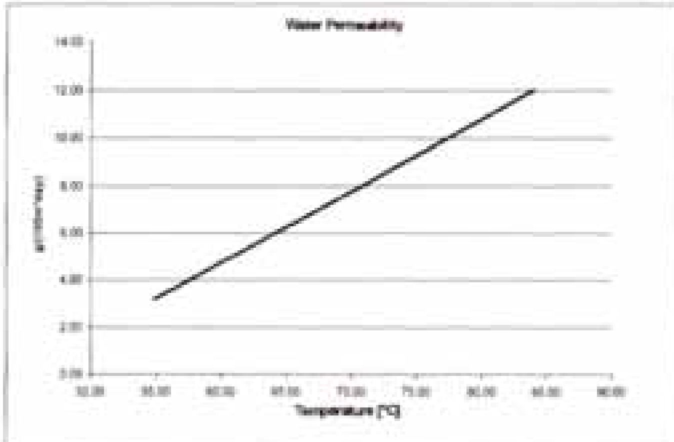
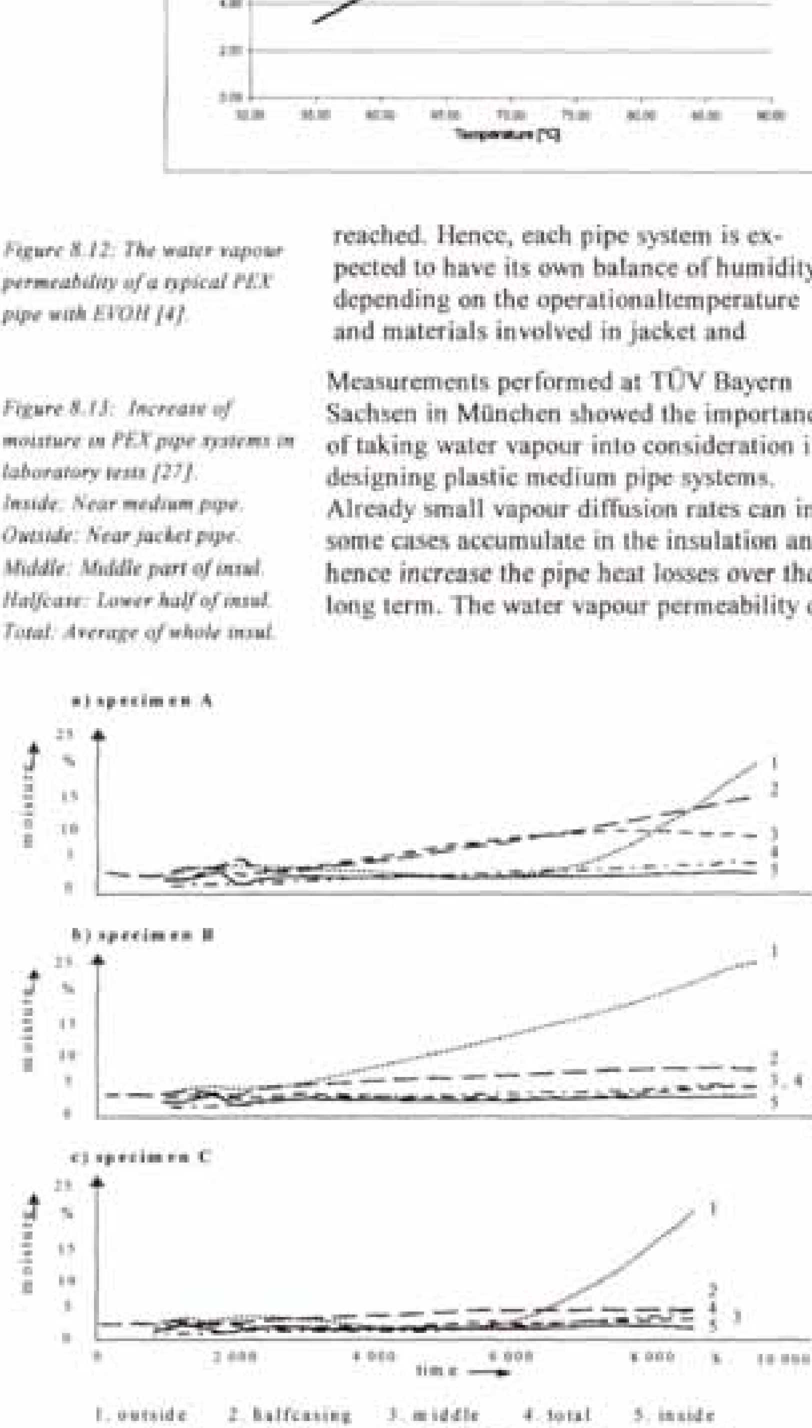


Figure 8.12: The water vapour permeability of a typical PEX pipe with EVOH [4].

reached. Hence, each pipe system is expected to have its own balance of humidity depending on the operationaltemperature and materials involved in jacket and

Figure 8.13: Increase of moisture in PEX pipe systems in laboratory tests [27].
Inside: Near medium pipe.
Outside: Near jacket pipe.
Middle: Middle part of insul.
Halfcase: Lower half of insul.
Total: Average of whole insul.



Measurements performed at TÜV Bayern Sachsen in München showed the importance of taking water vapour into consideration if designing plastic medium pipe systems. Already small vapour diffusion rates can in some cases accumulate in the insulation and hence increase the pipe heat losses over the long term. The water vapour permeability of a PEX pipe is shown in Figure 8.12.

Hence, the design of the pipe system including insulation and jacket has to be adopted to this vapour losses, so that the vapour can leave the system at as low equilibrium values for the moisture in the insulation as possible. Otherwise, the heat losses of the pipe system will increase.

In laboratory tests made by FFI [27], three different makes of PEX pipe systems with PU-foam and PE jackets and the same type of medium pipe have been investigated. The results showed that moisture accumulates during typical test times of one year at (water temperature 90°C, see Figure 8.13). Also it was shown that the water condenses along the cooler outside of the insulation (inside the jacket) which was kept at room temperature, in the worst case can it accumulate at low points of the pipe system.

For all test cases, an increase of the heat conductivity between 8 and 16 % during one year could be found without reaching equilibrium. However, the results are preliminary and final conclusions about water diffusion in PEX pipes cannot be drawn yet. But it seems appropriate that in the further development of plastic pipe systems, more attention should be laid on the water permeability of the outer jacket for venting out the water vapour.

8.6 Properties of pipe insulation

The heat loss of plastic pipe systems is in general well described in the plastic manufacturers' plastic pipe documentation. The Swedish District Heating Association has in 1998 ordered some tests of the insulation standard for plastic pipe systems in order to check the manufacturers' values. The measurements were made by the Technical University of Chalmers at the Institute for Building Physics [38]. Three test objects with dimensions DN 50 available on the Swedish market have been selected:

- Lögstör LR-PEX
- ABB Aquawarm
- Wirsbo ECOFLEX.

The Lögstör and the ECOFLEX systems are according to Table 2.1. The Aquawarm system consists of a glass-wool insulated jacket-pipe and an inner feed pipe, trough which a Cu-pipe (or also a PEX pipe) can be fed. The pipe system was also used for PEX-pipe systems in the 1980-ies in Sweden. In this test the medium pipe was made of copper.

The measurements were made in a static laboratory test in accordance with the Standard SS-EN253.

Figure 8.14 summarises the results for the effective linear thermal transmittance U (W/(mK) of the pipes as a function of the mean temperature of the pipes = $[0,5 \times (T_{\text{inside media pipe}} + T_{\text{outside jacket pipe}})]$.

Table 8.5 summarises the values for the temperature difference between medium pipe and outer jacket of 50°C. The table indicates also typical values presented in the product information. As can be seen, most of the values agree very well with the test values.

By the same test institution, also the properties of wet insulation have been tested [39]. Figure 8.15 shows the change of the thermal conductivity with increased content of moisture in a block of PUR insulation. The figure shows that already a moisture content of 20 % doubles the thermal conductivity and therefore the heat losses in PUR. The results in Figure 8.13 show the same order of moisture content in pipes, but with inhomogeneous distribution, which resulted in lower increase of the thermal losses measured in pipes. But it can be concluded that pipe designs allowing accumulation of water vapour will lead to increase of the thermal losses of plastic pipe systems.

Figure 8.14: Linear thermal transmittance as as function of mean temperature for medium pipes ND 50.

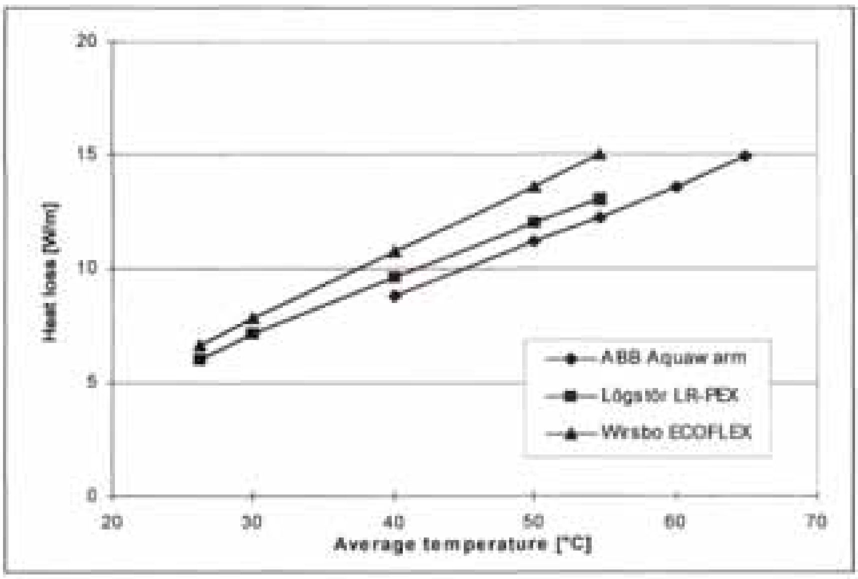


Figure 8.15: Thermal conductivity in PUR as a function of the moisture content measured in a block of PUR foam with $\rho = 30\,kg/m^3$

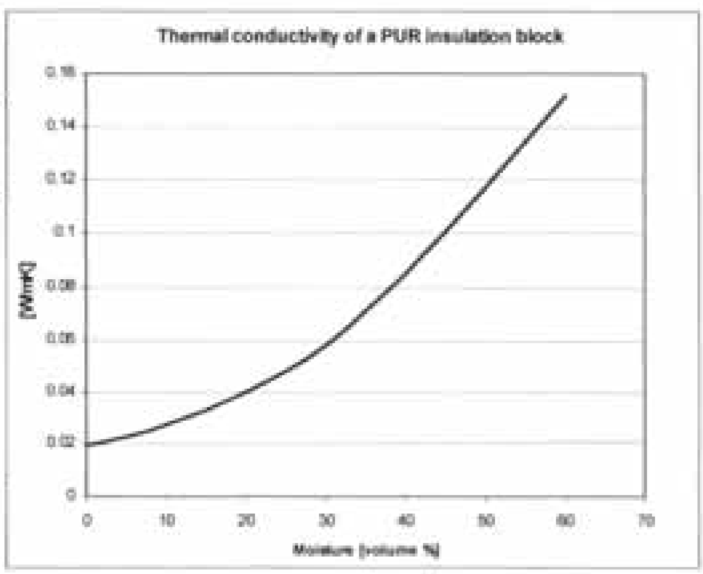


Table 8.5: Comparisonof measured values and product catalogue values for the heat loss at a temperature difference of 50°C (d_i = diameter inside medium pipe, d_o = outer diameter of jacket pipe).

Make	Dimension	Insulation	Loss (ΔTm=50°C)	Loss (Catalogue)
	d_i/d_o		W(mK)	W(mK)
Lögstör LR/PEX	50/110	Pu	12.0	13.7
Aqwuawarm-Cu	54/186	Mineral wool	11.2	18.4
Wirsbo ECOFLEX	50/160	PEX-foam	13.6	13.3

Table 8.6: Comparison of principle material differences between plastic medium pipe and steel pipes for district heating systems.

	Limitation/risk	Plastic pipes	Steel pipes
Service life	temperature (°C)	90-95	120 -140
	pressure (MPa)	0.5-0.6	1.6
Oxygen permeation	diffusion barrier	EVOH (AL)	Steel
	corrosion	no problem with adequate system	no problem
	combination with steel pipes	at least 10 % steel (30% Germany)	100 % steel
Water vapor permeation	diffusion barrier	plastic material	steel
	wet insulation	low when optimized	no
	heat loss	can increase or vary with time	no increase due to internal water

8. 7 Material aspects - summary

The description of the basic material properties of plastic medium pipes elucidates the principal difference between plastic medium pipe systems and conventional steel pipe systems (see Table 8.6):

The table makes it obvious that plastic pipe systems must be designed with caution. There are several material limitations in pressure and temperature which must be observed:

- Plastic medium pipes should not be installed without knowledge of the operating conditions of the system. The temperature control profile must be known. The pipe manufacturer should give his consent to the application based on the control strategy.

- Plastic medium pipes with oxygen permeation barriers will normally not give cause for corrosion. The remaining oxygen permeation is comparable with "normal" oxygen leaking in typical systems. However, it is recommended that if plastic pipes are mixed with steel pipes, the amount of steel pipes (or of other steel surfaces) is at least 30 % of the plastic pipe surface. In Scandinavia it is generally believed that the amount of steel surface could even be lower. In [18] an amount of 10 % is considered to be sufficient.

- Water vapour diffusion through plastic pipe systems is an important factor determining economy and the long term function of the plastic pipe network. The permeation of water through medium pipes should be in balance with permeation of the outer jacket and the insulation. Because permeation is temperature depending in all those materials (medium pipe, insulation, jacket), each system will find its own equilibrium depending on operating temperature and achievable jacket temperature. However, in practice this means that the thermal conductivity will increase until an equilibrium is reached. This can take years.

The question of the influence of water vapour on the insulation properties and its long term behaviour must be further evaluated.

9 Plastic Medium Pipe Systems and Risk for Corrosion

As to district heating systems, there should not be a difference for the specifications of the water quality in a system with plastic pipes compared with traditional steel systems. In both cases, the system components besides the piping system, such as heat exchangers, pumps, valves, vessels, etc., include a variety of materials such as steel, copper, brass and others, so the risk for corrosion is present if certain measures are not taken to assure the water quality. These measures are summarised in the form of recommendations, see e.g. [28].

However, in special cases, especially in local low-pressure temperature networks, deviations from these recommendations can be allowed, as exemplified in Chapter 9.7.

Table 9.1: Some recommended water quality values for district heating.

	Unit	Indirect systems *)	Direct systems *)
pH-value (25°C)		9.5 - 10	9.5 - 10
Hardness	°d mmol (Ca + Mg)/kg	<0.178 <1	<0.089 <0.5
Oxygen content	mg/kg water	< 0.02	< 0.02

*) Indirect systems are such systems where the vessel and distribution system are separated by heat exchangers.

9.1 District heating water quality

Heat distribution systems comprising mainly or partially plastic pipes, will principally be confined or limited to a lower power range below 10 MW (larger systems will have dimensions and temperature/pressure characteristics not suitable for plastic pipes). For these systems, three important parameters govern the water quality and are according to [28, 29] recommended to be as can be seen in Table 9.1.

Other contents such as concentration of ions, iron, copper and ammonia are not specified for small systems but are left to the judgement of the plant operator according to the local conditions.

Hardness and pH-value are only depending on the quality of the raw- and feed water, respectively, and their need of control is unaffected by the presence of plastic pipes.

Hardness:

Ions contributing to the hardness of water are Ca^{2+} and Mg^{2+}. In the presence of bicarbonate (H_2CO_3) these ions can form scaling carbonates on surfaces of pipes and heat exchangers.

pH-value:

Steel has the lowest corrosion reactivity at pH-values 9.5 - 10. This value is also quite appropriate for copper, but it is important that for copper the pH-value does not pass 10. Aluminium must not be used at such pH-values.

Conductivity:

The electrical conductivity of water is a measure of the salinity of the water and varies widely with local conditions. Because the conductivity is affecting the strength of corrosion reactions, it is important to know the difference between softening and desalting. Softening only removes Ca- and Mg-ions and leaves the salinity (i.e. the content of charged ions in the water) more or less unchanged. Desalination treatment (e.g. by means of ion-changers and/or semipermeable membranes) takes care of all ions and supplies a water with a low degree of ions and a conductivity less than 10 µS/cm. Such installations are very often used for treatment of the feed water in district heating systems.

Oxygen:

By far the most important question concerning plastic pipes is the diffusion of oxygen and its contribution to the content of oxygen in the district heating water. The amount of available oxygen is directly affecting the amount of corrosion products to be expected in a given system. As it is not realistic to achieve an absolute zero oxygen level because of leaks, feed water, maintenance work, and so on, the maximum oxygen level which can be tolerated is recommended to be *0,02 mg/kg water*. A German recommendation states 20 ppb oxygen in water, which is about twice the northern recommendation.

9.2 Tolerated levels of oxygen in district heating networks - corrosion risks for ferrous and non-ferrous metals

Corrosion, erosion and scaling in district heating systems can be principally avoided if the following measures are observed:

- absence of oxygen
- low content of hydrogen (i.e. pH 9,5-10)
- low electrical conductivity
- low hardness
- absence of particles and sladge
- low water velocity (especially for copper: < 2 m/s).

In practice, it might be difficult, especially in smaller systems, to have control of all these parameters at the same time, and plant owners have the responsibility to judge the risk of corrosion and its costs against the costs for measures to avoid them.

The types of common corrosion are:

Oxygen consuming corrosion (cathode reaction):

$$2\ Fe + O_2 + H_2O \rightarrow 2\ Fe(OH)_2$$

The metal (iron) disolves in the presence of oxygen and forms metal hydroxide. The reaction rate of the process increases with temperature. (In open systems, however, the solubility of oxygen in water decreases with the temperature and hence the corrosivity is highest at about 80°C, and decreases versus 0 at 100°C). The iron(II)hydroxide $Fe(OH)_2$ can further react with oxygen by forming the usual "rust" iron(III)oxide:

$$4\ Fe(OH)_2 + O_2 \rightarrow 4\ FeOOH + 2\ H_2O$$

In a further oxidation stage, especially at higher temperatures, the iron(II)hydroxide can also oxidise to magnetite:

$$3\ Fe(OH)_2 \rightarrow Fe_3O_4 + H_2 + 2\ H_2O$$

Hydrogen producing corrosion (anode reaction):

$$Fe + 2H^+ \rightarrow Fe^{2+} + H_2$$

This corrosion process presumes the presence of hydrogen ions and is very reactive in acid environments, i. e. pH less than 4 and decreases with increasing alcalinity. It is negligible at pH values greater than 9,5.

Hence the presence of water and oxygen is a necessary prerequisite for the occurrence of common corrosion.

Other types of corrosion which also are influenced by the presence of oxygen are *pitting and crevice corrosion*, i. e. corrosion which is favoured by local enrichment of oxygen due to inhomogenities in the material or due to slits, scales, etc., which protect the water from the main stream and enable it to be enriched in oxygen.

At pH-values less than 7, also copper can undergo corrosion, and under special circumstances (low HCO_3/SO_4 ratio), even pitting.

Hence, in order to avoid any of these types of corrosion, the following measures should be taken:

- **The oxygen content must be as low as possible, at the highest 0,02 mg per kg water.**
- **If the oxygen content is higher, water treatment must be applied to reducing the oxygen content to acceptable levels.**

Water treatment can be done by thermal boiling or chemical degasification (i.e. by means of addition of natriumsulfate, hydrazine, tannine and other reduction media). For more details see Chapter. 9.4.

9.3 Combination of steel and plastic pipes and risk for corrosion

So far the use of plastic pipe systems is considered, two questions arise for the practical operation:

- How much oxygen do plastic pipes add to the systems ?
- How do the metallic parts react on the presence of the increased oxygen content, i.e. how to combine plastic pipes with steel or copper pipes or which impact do plastic service pipes have on direct connected steel radiators ?

The reason for the fear about the "oxygen poisoning" of district heating systems due to plastic pipes is founded on experiences of the 70's and early 80's when uncritical use of unprotected plastic pipes in floor heating systems led to fatal consequences. Since that time at least PEX-pipes have been supplied with diffusion barriers, in most cases made of ethylenevinylalcohol or by aluminium. Aluminium/PEX compound pipes are mostly used in smaller dimensions and for special applications.

Barriers made by ethylenevinylalcohol (EVAL or EVOH) on the other hand are plastic products and exhibit a small, non-zero diffusion rate for oxygen as shown also in Figure 8.11. Measurements of the oxygen permeability in PEX-pipes have been made in Sweden, Denmark and Germany, at different times and with different pressures [11, 25, 26, 4].

Table 9.2: Permeation of oxygen σ (O_2-PEX) for different dimensions of PEX-pipes with oxygen barrier EVOH.

Dimension	d_i	V (L=10m)	σ (O_2-PEX)
mm	m	m³	g/(m².d)
22 x 3.0	0.016	0.00201	3.25E-01
28 x 4.0	0.02	0.00314	2.60E-01
32 x 2.9	0.0262	0.005307	2.00E-01
40 x 3.7	0.0326	0.008343	1.60E-01
50 x 4.6	0.0408	0.013067	1.27E-01
63 x 5.8	0.0514	0.020739	1.01E-01
75 x 6.9	0.0612	0.029402	8.50E-02
90 x 8.2	0.0736	0.042523	7.07E-02
110 x 10	0.09	0.063585	5.78E-02

The conclusion from these measurements is that laboratory measurements are difficult to carry out at low oxygen contents due to a usually low amount of pipe surfaces involved in the tests. The results differ therefore also from laboratory to laboratory. However, by means of field experience, reliable minimum values for the permeability can be derived, which are reasonably conform with the results from laboratories.

The values from Figure 8.11 indicate a spread of the specific permeability σ at T = 80°C of the plastic pipe barrier EVAL for test pipes with a diameter of 25 - 30 mm:

$$10^{-9} < \sigma < 7\cdot10^{-8} \text{ g/(m}^2\cdot\text{s}\cdot\text{bar)}.$$

Corresponding values for pipes with the same dimensions as above but without a barrier are:

$$7\cdot10^{-7} < \sigma < 2\cdot10^{-6} \text{ g/(m}^2\cdot\text{s}\cdot\text{bar)}.$$

The oxygen permeability for barrier protected PEX-pipes is about a factor 10 to 2000 smaller than that for unprotected pipes.

It is therefore of great importance to evaluate field measurements in order to analyse the eventual consequences from oxygen leakage to system components. The measurements from different laboratories summarised in Figure 8.11 give for T = 80°C the following maximum value for the oxygen permeability through PEX pipes:

$$\sigma = 7\cdot10^{-8} \text{g/(m}^2\cdot\text{s}\cdot\text{bar)}.$$

With this value, the following oxygen diffusion rate can be calculated for various pipe dimensions (Table 9.2):

It should be noted that the results from Denmark (Amby, 1988) indicates σ-values which are a factor 10-100 smaller, the reason for that is not quite sure. It is obvious from Table 9.2 that the oxygen permeation of PEX decreases with increasing dimensions due to the decreasing area/volume ratio.

Hewing cites measurements of oxygen permeation for both types of pipes with and without oxygen barrier, see Figure 9.1. It should be noted that according to DIN 4762 for floor heating pipes, the permeation D, should be less than 0.1 g/m³ per day. The maximum value 0.08 g/m³ per day for the pipe with oxygen barrier at 60°C corresponds to a σ-value of $6.4 \cdot 10^{-8}$ g/(m²·s·bar) and is therefore quite close to the value cited above from other manufacturers.

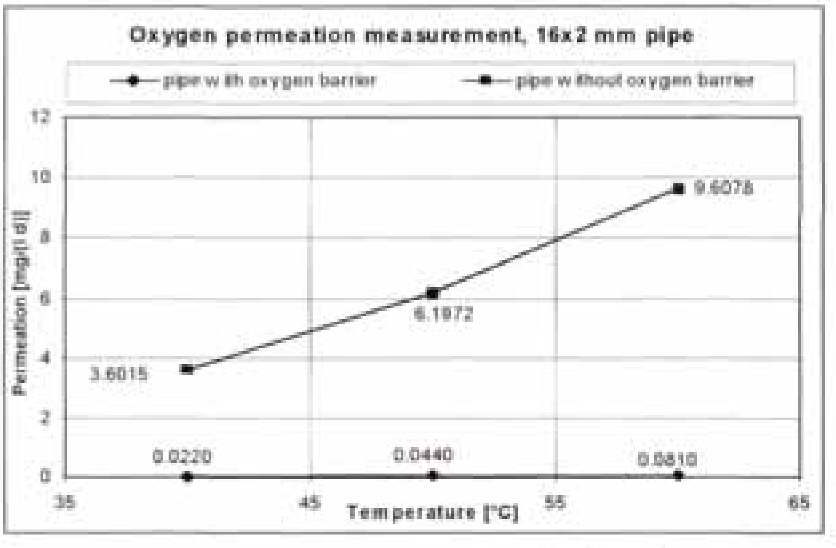


Figure 9.1: Oxygen permeation for Hewing pipes 16 x 2 mm.

As an example, Table 9.3 shows the connection between oxygen diffusion and the amount of corrosion products due to a pipe system with 2 x 500 m EVAL-PEX-pipes. Diurnal results are presented for 80°C and annual results for a temperature mix in a 80/60°C district heating network. In this example, the annual corrosion of a 10 m steel pipe caused by 500 m plastic medium pipe of the same dimension is about 3.3 µm/year and the anual collected sludge in form of magnetite or $Fe(OH)_2$ for the given temperature mixture is between 14 and 80 g, depending on the pipe dimension.

Although the expected corrosion of steel pipes due to plastic medium pipes is very slow, if equally distributed, this might not be the case. In Germany [4], the influence of local corrosion was estimated and compared with the influence of evenly distributed corrosion. For one application, in which the water volume of plastic medium pipes was 4 times that of steel pipes, the maximum pitting was determined to be < 0.1 mm in 35 years compared to evenly distributed corrosion which is estimated to be < 0.001 mm in 35 years. Hence for the reason of pitting, the amount of steel pipes in a combined plastic pipe/steel pipe net should not be too small.

It becomes obvious that the corrosion effects due to PEX-pipes with EVAL or EVOH barriers are negligible. Because of the risk of pitting, however, it is recommended that the volume of steel pipes or corresponding steel areas should be at least 10 % of that of plastic pipes. (The German recommendation is that the amount of steel pipe surfaces be at least 30 %).

There are, however, no indications for PEX-pipes being the cause of enhanced occurrence of pitting or pitting corrosion. The occurrence of common corrosion due to plastic pipes is comparable with the corrosion caused by the normal residual oxygen.

Oxygen equilibrium

The Danish Technological Institute (DTI) reports on measurements of the corrosion dynamic on steel pipes and steel radiators [11]. From these measurements, a dynamic corrosion factor f_c as a function of the flow velocity can be derived. It is shown in Figure 9.2.

The corrosion factor f_c determines how the oxygen diffuse through the water and how fast it can interact with the pipe walls. Its influence can be described by the following equation:

$$c_t = (c_1 - c_2) \cdot e^{-t \frac{f_c \cdot A}{V}} + c_2$$

with c_1, c_2 c_t being the concentration at the beginning, at the end at the time t. A the steel surface area and V the water volume of a closed system.

In Table 9.3, all results are calculated without the corrosion factor presuming that all oxygen produced by the PEX-pipes is consumed immediately in the steel pipes connected after the plastic pipes. However, if a dynamic corrosion factor is taken into account, and if it is further assumed that there are no other sources or sinks for the oxygen, a balance will be established between the produced and consumed oxygen. The slower the corrosion factor, the less oxygen is consumed and the higher the equilibrium concentration will be. This equilibrium value is 100 microgram oxygen per litre water for σ

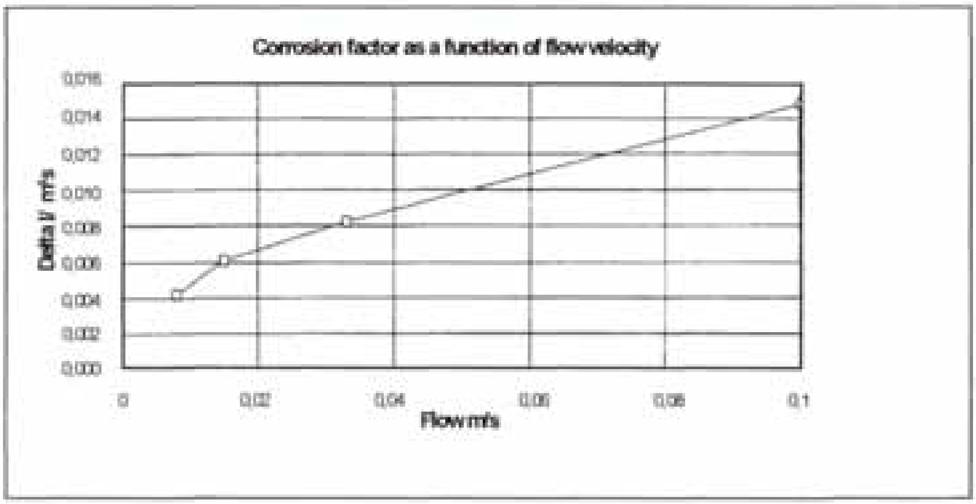


Figure 9.2: Corrosion factor as a function of the flow velocity.

$= 7 \cdot 10^{-8}$ g /(m²·s·bar) for the permeation in 500 m plastic pipes and 10 m steel pipes. In order to get the equilibrium concentration of oxygen in water down to 20 µg/l, at least 50 m steel pipes should be combined with 500 m plastic pipes.

It can be stated that the combination of 90 % PEX-pipes with oxygen barrier and 10 % steel pipes is theoretically sufficient to bring down the oxygen level in any case to tolerated values without exhibiting a prohibitive corrosion risk in the system.

Results for PB and PP plastic pipe systems are for the moment not known.

9.4 Water treatment

As to plastic pipe systems, all usual methods for water treatment in steel pipes are also recommeded except the use of such inhibitors and other chemicals which might contribute to accelerated break-down of the oxygen bridges of the PEX material.

Softening

Softening is applied primarily for the reduction of calcium and magnesium ions contributing to sludge and scaling in the system. In general, Ca- and Mg-ions are exchanged in ion-changers against Na-ions by means of addition of NaCl (salt) to the ion-exchange bed. However, a too large salt content can lead to pitting in steel pipes or other corrosion in steel pipes.

Deionization (Desalting)

The water is desalinated by leading it through *both* a cation *and* an anion filter. Beds containing HCl and NaOH respectively are removing all types of common salts dissoluted in water, such as $Mg(HCO_3)_2$, $CaSO_4$, NaCl or SiO_2. Deionized water can also be produced through inverted osmose by pumping water through a semipermeable membrane. Deionized water gives low

Table 9.3: Diffusion of oxygen and corrosion products in PEX-pipes with oxygen barrier EVAL. The sludge is presumed to consist of 50 % Magnetite and 50 % $Fe(OH)_2$.

Dimension [mm]	[g O_2/d] (80°C)	[g /a] (temp mix) 80/60 °C	[g/d] (80°C) $Fe(OH)_2$+ Fe_3O_4 (sludge)	[g/a] (temp mix) 80/60 °C sludge	annual corrosion (mm/yr)
22 x 3.0	0.07	4.91	0.21	15.72	$3.3 \cdot 10^{-3}$
28 x 4.0	0.08	6.14	0.26	19.65	$3.3 \cdot 10^{-3}$
32 x 3.0	0.11	7.98	0.34	25.54	$3.3 \cdot 10^{-3}$
40 x 3.7	0.13	10.01	0.43	32.03	$3.3 \cdot 10^{-3}$
50 x 4.6	0.17	12.53	0.53	40.08	$3.3 \cdot 10^{-3}$
63 x 5.8	0.21	15.78	0.67	50.50	$3.3 \cdot 10^{-3}$
75 x 6.9	0.25	18.79	0.80	60.12	$3.3 \cdot 10^{-3}$
90 x 8.2	0.30	22.60	0.96	72.30	$3.3 \cdot 10^{-3}$
110 x 10	0.37	27.63	1.18	88.42	$3.3 \cdot 10^{-3}$

amount of sludge, low scaling and low risk for corrosion.

Deoxygenising

These methods can be used in connection with plastic medium pipes. Several methods are commonly applied.

Thermal degassing

The most common way is to make the water boil under vacuum at low temperatures.

Chemical deoxygenising

The water is treated with chemicals reacting with oxygen. Among chemicals to be used are Na_2SO_3 or hydrazine (N_2H_4). Na_2SO_3 should be used carefully due to risk of corrosion on copper. The use of hydrazine should be combined with a pH control system. *However, for environmental reasons, a ban of hydrazine for use in district heating is expected to be put into effect within a couple of years.*

Other additions are Tannin or organical compounds. None of those has been evaluated for plastic media pipes.

Inhibitors

Inhibitors are water additives provided for corrosion prevention, i.e. deionized water can be treated with NaOH (ca 2 g/m^3) for balancing the pH value between 9.5 and 10. If only softened water is used, the amount of NaOH additives depends on the amount of HCO_3 dissoluted in the water.

ATTENTION: Generally speaking should additives to the water in plastic pipe systems only be used when it is demonstrated for certain that they will not have a negative influence on the strength and working life of the pipes. However, there is no evidence that the processes described above have negative impact on plastic pipes.

9.5 Erosion-corrosion

Erosion corrosion occurs mainly on material containing copper such as copper pipes and brass couplings, a.o. This type of corrosion occurs in water with relatively high oxygen content and high flow velocity (or locally modified water flow yielding high velocity, for example in some types of couplings). The water flow erodes the protecting layer of copper oxide and thus offers fresh copper surfaces to the oxygen in the water building a protecting layer which gets eroded, and so on. The process accelerates with decreasing pH value. The maximum recommended flow rate for avoiding erosion corrosion is 2m/sec. This is a velocity which is reasonably high for plastic medium pipes also with respect to pressure drop and noise generation.

9.6 The Grudis-connection

One way of avoiding corrosion in plastic medium pipe systems was developed through the 1980s when the permeation barrier was not yet available, at least in plastic pipes with larger dimensions. The Swedish district heating group of Studsvik developed with the GRUDIS-principle one way of disregarding of the oxygen eventually diffusing through the plastic pipes.

By designing the secondary or local net completely according to domestic hot water standards, the corrosive influence of the oxygen was overruled by the material quality of the components. Furthermore, feed water could be added untreated to the system and consequently domestic hot water could be prepared directly in and taken from the net. Therefore, oxigenated water was continuously circulated through the pipes without any risk for corrosion. Floor heating or plastic piped radiator heating could also be connected directly to the system. In existing buildings, the heating circuits were separated by a stainless steel heat exchanger from the plastic pipe network. About 20 Grudis systems were built during the 1980s and are still operating safely. For more details about the system see Chapter 4.1.4.3.

9.7 Plastic pipes and water quality - experiences

The conclusions above indicate that a combination of steel and PEX-pipes is in most cases a technically reliable solution. However, the designer of piping networks has to be aware about the role of the oxygen diffusion barrier and must make sure that enough steel is present in order to let the penetrating oxygen be consumed in a safe way.

Some examples should illustrate the use of plastic pipes.

9.7.1 Field studies in Langholt, Denmark

A local district heating system with totally 3500 kW for around 200 consumers has been built in 1991 in Langholt, Vendsyssel, Denmark [25]. The distribution network is built in a combination of PEX and steel pipes. The plastic pipes have the dimensions DN 22 - 50 and all steel pipes have dimensions DN 60 - 130. About 7800 m (trench) plastic pipes and 2000 m steel pipes have been applied in the net. Totally ca 64 % plastic pipes are installed, from which about 80 % are service pipes to the consumer stations. The amount of water distributed at measurement times was 56 m³/h, the design temperatures were 80°C (supply) and 35°C (return), respectively. The water was treated for controlling pH value and oxygen content.

In one of the branches of the network, the following test points were placed measuring oxygen and other water quality parameters:

1. Water leaving the hot water plant
2. Water entering the plastic pipe main line
3. Water in the point of return in the plastic system (most far away from the heating plant)
4. Water coming back to the steel pipe main line
5. Water entering the heating plant.

The oxygen treatment was stopped before start of the final measurements.

The measurements were performed with a mobile measurement equipment extracting a small test flow of the water, which after the measurements has been dumped to the sewage channel. The system measured the oxygen content and the temperature of the water and the results were recorded with a data logger.

The measurements carried out in December 1991 and March 1992 showed very low oxygen concentrations of $1 - 3 \cdot 10^{-6}$ g/l at all measurement points (see Figure 9.3). During the summer season, however, large variations of the oxygen levels, from below $10 \cdot 10^{-6}$ g/l up to greater than $100 \cdot 10^{-6}$ g/l could be found, with very fast jumps in the oxygen concentration from low to high. A nearer analysis of the operational log book showed a correlation of this oxygen penetration with the steam cushion of the hot water accumulator.

It is a very common problem in hot water heating plants, that the steam cushion in accumulators, which should prevent the penetration of oxygen through the top water layer of the accumulator, does not work satisfactorily if the accumulator temperature is too low. The steam cushion can collapse with an insucking of fresh air and contamination of the water as a consequence. Further measurements confirmed this behaviour.

The experiences from laboratory analyses carried out in parallel with the field tests showed also that the amount of plastic and steel pipes in the system only can account for an equilibrium concentration of $0.25 \cdot 10^{-6}$ g/l oxygen, i. e. below the possibilities for measurement with the equipment used. This shows that also the low measured content of oxygen must originate from elsewhere, but not from the plastic pipes.

Parallel to the oxygen content, also other water quality parameters such as ion contents, hardness and pH-value, were meas-

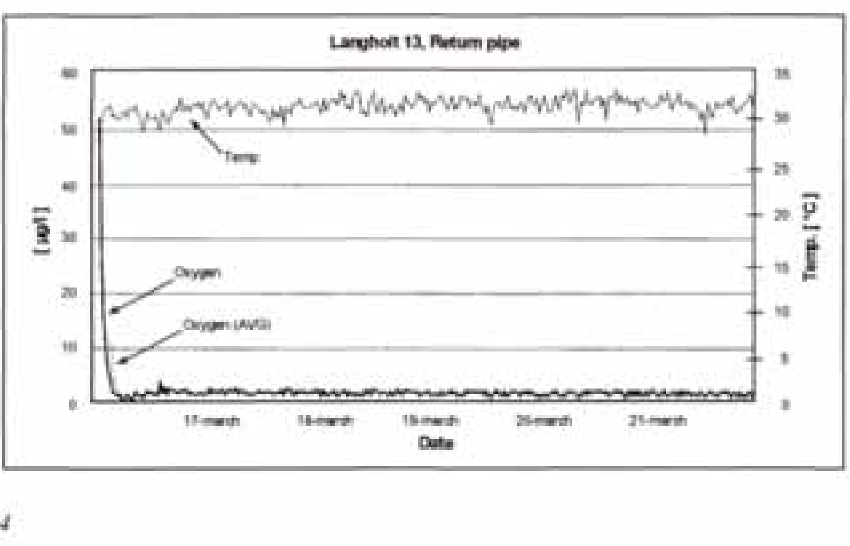


Figure 9.3: Oxygen concentration in the return plastic pipes of the Langholt system (point 4 in March 1992).

ured. No abnormal content or indication for scaling and/or fouling could be stated.

9.7.2 *AGFW Project Völk lingen Sonnenhügel and Großrosseln Warndt*

In these two projects, plastic medium pipes and steel pipes were successfully combined. Based on the measured values for oxygen permeation (see Figure 8.11), the oxygen content and the annual quantities of deposits have been estimated and compared with field experience. The most important results are summarised in Table 9.4.

Initially high corrosion and sludge rates could thus be reduced to reasonable values. However, the biggest problem with this systems has been deformation of scales, and deposits, sludge and consecutive problems in sludge filters, heat meters, control valves, and sometimes even heat exchangers.

One of the conclusions of the Finnish experience has been that water treatment for reducing the oxygen content was possible even with large permanent sources of oxygen. Lately, certain inhibitors have been found to give satisfying results in avoiding these problems.

Table 9.4: Influence of oxygen on corrosion in two German projects.

	Unit	Völklingen Sonnenhügel	Großrosseln Warndtwiese
Operating temperature			
supply	°C	90/65	90/65
return	°C	50	50
Length of pipes			
steel pipes	m		430
plastic pipes (incl. service pipes)	m	1350	485
Water volume in plastic pipes	m³	5	11.2
Steel wall surface	m²	1250	10080
Loss of wall thickness after 35 years			
even distribution	mm	<0.001	
maximum	mm	< 0.1	
Magnetite deposit	kg/yr	1.7	3.8
Estimated O_2 concentration			
winter	µg/l	2.5	1
summer	µg/l	8	3.5

According to the estimates presented in the table, no problems with corrosion or oxygen content were expected. Neither has the field investigations shown any unexpected values of the oxygen content or sludge. No corrosion problems have so far occured.

9.7.3 *Finland*

Finland is one of the pioneer countries for plastic pipe systems with projects dating back to the 1960's. However, practically all experiences have been gained with plastic medium pipes *without* an oxygen permeation barrier. Because of the high oxygen penetration in these pipes, the water was treated with hydrazine or similar products in order to prevent corrosion of boilers and other equipment with steel components.

9.7.4 *Sweden*

As also described in Chapter 5 and Appendix C1 two demonstration projects with plastic pipes have recently been built in Sweden. The net in Landskrona consists of a combination of copper and plastic pipes (LR-PEX), whereas the net in Enköping is completely built with plastic pipes of Ecoflex type. In both systems, the influence of oxygen is measured by means of a corrosion measurement equipment and corrosion steel coupons.

In Enköping the corrosion coupons and the corrosion sensor were installed in the district heating water supply pipe in the substation. The net consists of 1030 m plastic pipes directly connected to steel radiators in the connected houses. The measurements were taken from the beginning of the plant operation.

The corrosion sensor measures a galvanic current between a reference probe and the test probe in the water as it is shown in Figure 9.4. From initial high values the value stabilises at about 6 µA after 10 weeks. The main reason for high initial value is the oxygen in the fresh water and an initial high supply of additional fresh water until deaeration has been accomplished in the whole net. The oxygen is consumed by the directly connected radiators of the houses. The corrosion coupons showed a homogene-

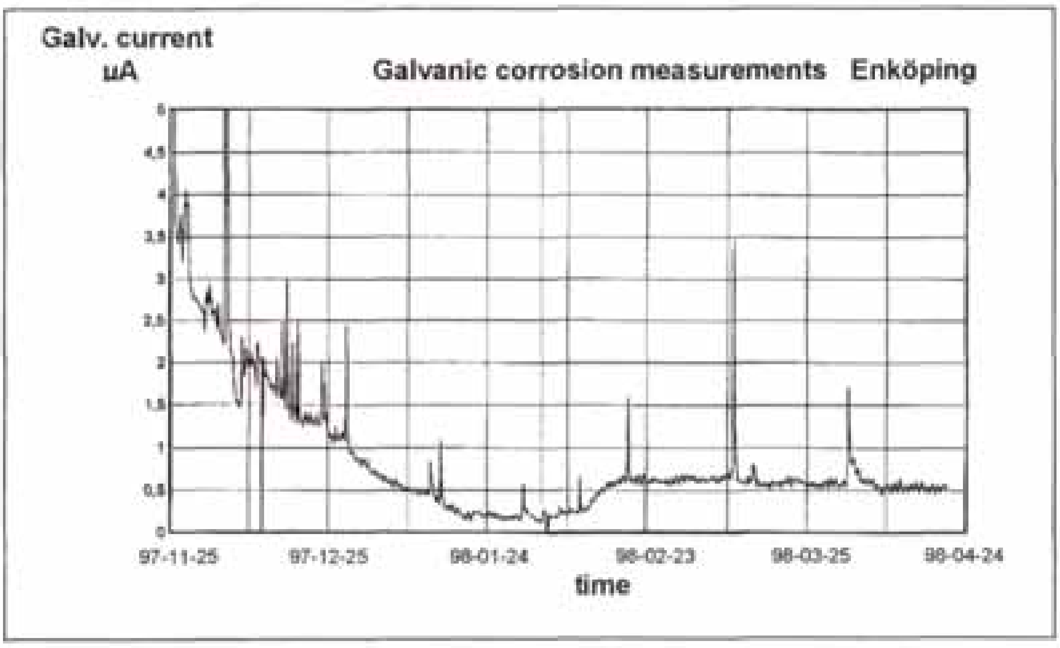


Figure 9.4: Galvanic corrosion probe measurements during 3 months after operation start in Enköping, Sweden

ous magnetite layer indicating a corrosion intensity of 1.2 µm/yr. No sign of pitting was found.

Similar measurements with corrosion coupons were performed in the net in Landskrona. There 3000 m Cu pipes were connected with PEX service pipes. Measurements were performed for 3 months here in two places, one in a bypass to the heating plant, and one in a plastic service pipe to a consumer.

Also here, after initially higher values, the equilibrium corrosion intensity near the plant was determined to 2.3 µm/yr and another one near the consumer station in a plastic pipe was measured to be 0.9 µm/yr. There was no sign that the plastic pipes are a detectable source of oxygen. The relatively high value of corrosion near the heating plant indicates the existence of other oxygen sources within the plant (feed water supply and valve leakage).

From the equilibrium levels of oxygen in both nets it was concluded that the maximum oxygen content is below 5 ppb, which is below the oxygen limit for district heating systems in Sweden which is recommended to be about 10 ppb. Hence the plastic pipes cannot be considered to be a major source of oxygen in either net.

9.8 Plastic pipe systems impact on corrosion - Summary

The quality of plastic pipes, especially of PEX pipes has been drastically improved since the middle of the 1980's. For district heating applications, PEX pipes with an oxygen permeation barrier made of ethylenvenylalcohol is the most common type of medium pipe. These pipes exhibit - although they are not completely permeation tight - very low rates of oxygen permeation which, however, increase with temperature. That means that at the temperatures of 90°C the difference between unprotected and protected pipes is about a factor 30 - 100 depending on the make and type of barrier.

The other way of protecting pipes is with Al-foil laminate in between two plastic layers. Investigations in Germany and Sweden showed that such layers are very sensitive to delamination at high temperatures and that the protection could, but is not better than that for pipes with EVOH. For these reasons most manufacturers produce AL-protected pipes only in small dimensions and for special applications. The implication of this is that we have to live with a low amount of oxygen permeation from the outside air to the water. In general, this amount is very low and difficult to discern from other sources of oxygen.

Hence, one conclusion is that PEX pipes with oxygen protection barriers can be well combined with steel pipes or other steel surfaces. Calculations show that usually a steel area of 10 % of the plastic pipe area is enough for both avoiding pitting and too high (< 20 µg O_2/l) equilibrium concentration of oxygen in water, (for safety reasons, in Germany a 30 % amount of steel pipe surfaces is recommended). In such a system the evenly distributed corrosion will be less than 1µm steel layer per year, and pitting corrosion is expected to be less than 0.1 mm.

Problems can occur when the steel surface is too small. The situation can be severe if single component, such as a pump or the axis of a flow meter, are exposed to the water from plastic pipes. If there are not enough steel surfaces in the circuit, all material should be made in a quality for fresh water (like in tap water systems).

Usually, plastic pipes are not the only oxygen leaks in district heating networks and water treatment measures are undertaken by the utility. Although the recommendation of the manufacturer is to be careful with chemicals (because of the risk of affecting the plastics chemistry), the standard water treatments for degassing, softening, deionizing and corrosion protection with inhibitors can be used with concern. But tensides used for friction reducing effects must be avoided because of their effect of breaking down the oxygen bridges in the cross-linked polyethylene.

A general observation in some projects seemed to be that the initial amount of sludge collected in the filters is higher than in steel pipe systems. This problem was first seen in systems with unprotected pipes, but seems to exist also in new systems with protected pipes. The reason for this is not quite clear, neither is it clear, if plastic pipes are the primary cause of it. Instead the observed attitude of filling up small systems with untreated water can give an explanation for that. However, it is recommended to make very frequent filter changes in the start-up phase of a system and - eventually - install a larger sludge filter than normal.

10 Conclusions - Material

- Several crosslinking methods for PEX pipes are in use, resulting in different degrees of crosslinking and therefore different lifetime expectancies. The buyer should be aware of this fact and note the designations of the pipe manufacturer.

- Plastic medium pipes should not be installed without knowledge of the operating conditions of the system. The temperature control profile must be known. The pipe manufacturer should give his consent to the application based on the control strategy.

- Plastic medium pipes with oxygen permeation barriers will normally not give cause for corrosion. The remaining oxygen permeation is comparable with "normal" oxygen leaking in typical systems. However, it is recommended that if plastic pipes are mixed with steel pipes, the amount of steel pipes (or of other steel surfaces) is at least 30 % of the plastic pipe surface. In Scandinavia it is generally believed that the amount of steel surface could even be lower. An amount of 10 % is considered to be sufficien

- The oxygen content - as in conventional district heating systems - should be as low as possible, at the highest 0,02 mg per kg water.

- If the oxygen content is higher, water treatment must be applied to reducing the oxygen content to acceptable levels.

- The oxygen permeability for barrier protected PEX-pipes is - depending on the temperature - about a factor 10 to 2000 smaller than that for unprotected pipes

- Water vapour diffusion through plastic pipe systems is an important factor determining economy and the long term function of the plastic pipe network. The permeation of water through medium pipes should be in balance with permeation of the outer jacket and the insulation. Because permeation is temperature depending in all those materials (medium pipe, insulation, jacket), each system will find its own equilibrium depending on operating temperature and achievable jacket temperature. However, in practice this means that the thermal conductivity will increase until an equilibrium is reached. This can take years.

- Additives to the water in plastic pipe systems should only be used when it is demonstrated for certain that they will not have a negative influence on the strength and working life of the pipes. However, there is no evidence that normal water treatment processes described above have negative impact on plastic pipes.

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Section C

APPENDICES

C1 Plastic pipe system in Munksundet, Enköping Sweden

Application

In Enköping, Sweden, a project was carried out for connecting 44 detached one-family houses with existing electrical resistance heating to district heating. The system is a secondary 0.6 Mpa system separated by a local substation from the primary district heating network. The primary is built in steel and the secondary network is completely built in PEX. The system is providing heat to directly connected radiators and to a heat exchanger for direct tap water production.

Technical parameter

Year of construction:	1997
Type of Pipe System:	Ecoflex - Wirsbo Sweden
Medium Pipe:	PEX with EVOH
Secondary supply temperature:	80/65°C
Secondary return temperature:	40°C
Primary supply temperature:	100/70°C
Primary return temperature:	43°C
Total dimensioning power:	610 kW
Number of houses:	44
House connections:	
Tap-water	0.35 l/sec, 55°C
Radiator	10 kW (55/40°C)
Total trench length:	1197 m
Average length of trench per house:	27 m
Heat density:	0.94 MWh/m trench.

Description

For cost saving reasons, the system is kept in small dimensions by dividing the net in three parallel parts starting from the substation (see Figure 1). The substation is installed in a small wooden service building. The following pipe dimensions are used in the total system:

DN 32 76 m
DN 40 294 m
DN 50 657 m

With these dimensions, Wirsbo Ecoflex Thermo Twin pipes could be used (see Figure 2), supplying at maximum 250 kW per system.

As it can be seen from Figure 1, the pipe routing was made from house to house without branches in the ground. The ground was easy to dig with only 30 cm wide and 70 cm deep trenches through the gardens made by a chain digger. Alternatively, house owners could dig their own trenches. Obstacles like large bushes and trees, but also some times facilities of the garden, were avoided. Trenches and pipe installations were made by the same entrepreneur. The pipes were laid on 10 cm sand bed and sand filling to 10 cm above the pipes, the excavated material was used for refilling the remaining part of the trench. No signal cable or drainage pipe was installed.

Rate of exchange:
1 US$ = 8 SEK

House connection

A steel box was installed at the front wall of each house which takes up the ends of the connecting pipe and in which system by-bass, service valves and energy metering were installed. From here Cu-pipes were fed through the wall to the substation inside the house containing the hot water heat exchanger and the shunt/pump-group for heating, see Figure 3. The direct connected radiators are steel radiators with thermostatic valves and convector flanges on one side. A pressure difference control system avoids sound generation at high pressure levels. Every house has about 12 m² radiators resulting in about 25 m² steel surface.

Costs

Because the system is part of the Swedish program for conversion of direct electricity heating, the construction costs were carefully evaluated (basis 1997, no taxes and TWA included).

Main substation:	27 600 US$
PEX - Twin pipe distribution:	106 500 US$
(ground work 43 %)	
(pipe install. 57 %)	
House installations:	93 500 US$
Other costs:	8 100 US$

These costs include all work of entrepreneurs and subentrepreneurs and also all purchaser costs during construction, except planning costs. It can be seen that the average district heating connection costs per house are about 5 400 US$ for the complete system and 2 400 US$ for the plastic pipe distribution system, i.e. 89 US$/m trench.

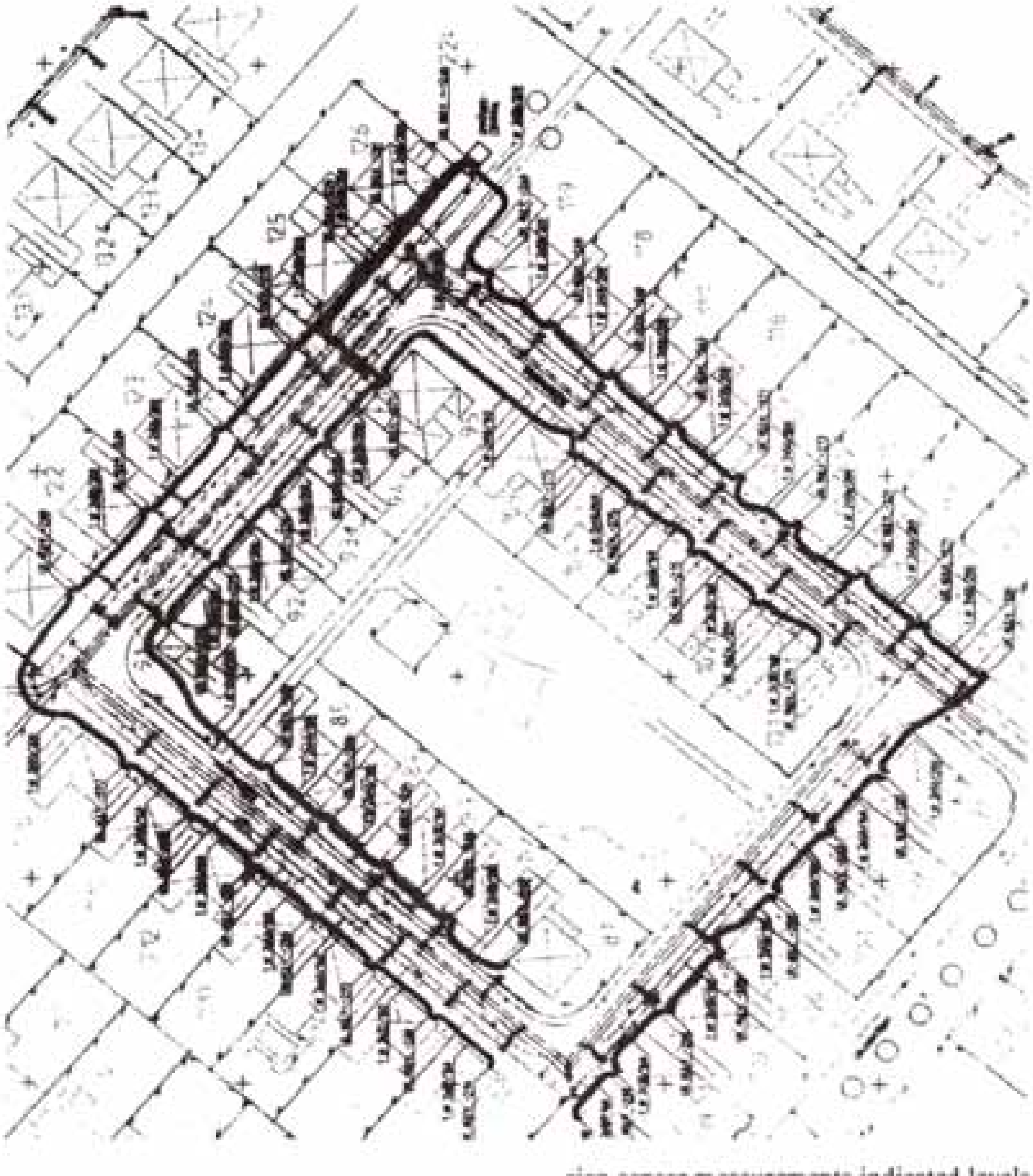
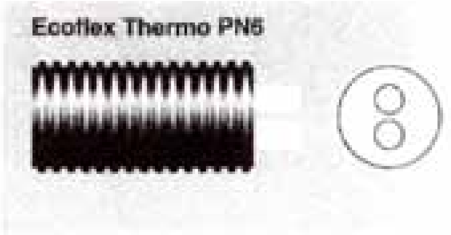


Figure 1: Scheme of plastic pipe system of Munksundet, Enköping, Sweden.

Experience and evaluation

A corrosion analysis system was installed directly when starting the system in November 97. After 77 days the first oxygen test plate was removed showing a corrosion of 1,2µm/yr, without showing any sign of local corrosion. At the same time galvanic corrosion sensor measurements indicated levels which were initially 10 times higher than after three months (because of the oxygen content of the untreated feed water). After three months, the corrosion sensor reached an equilibrium level indicating very low galvanic current of the same size as it is the case with normal steel pipe systems. The oxygen penetration rate was therefore estimated to be "very low". From the operational point of view, no incidents were reported.



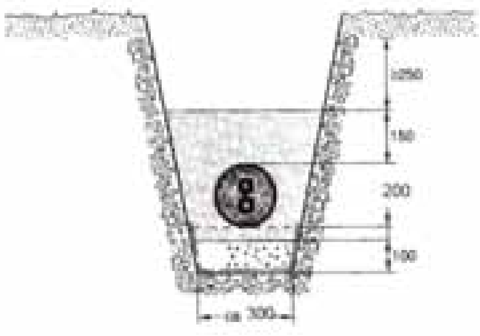


Figure 2: Ecoflex Thermo Twin System

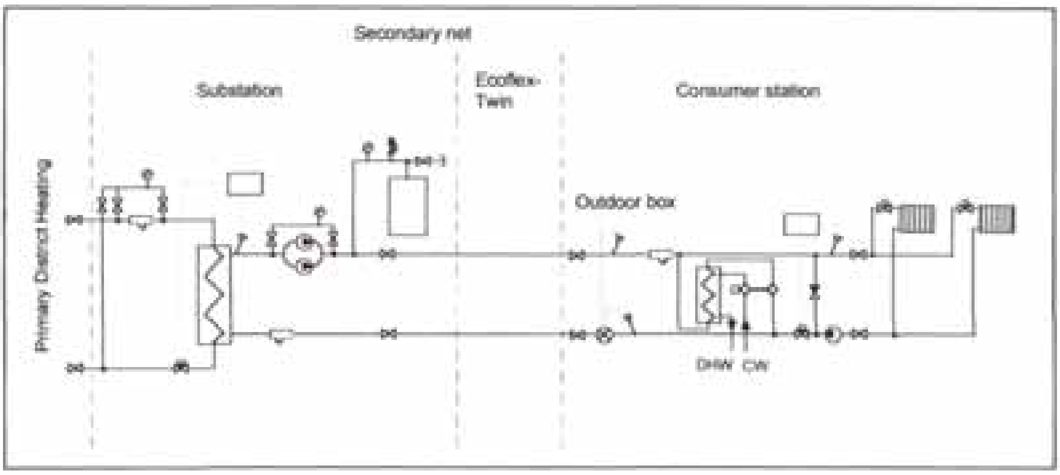


Figure 3: System layout for connection of 44 detached houses to district heating, Munksundet, Enköping.

C2 Plastic pipe system in Espoo, Finland

Application
In Espoo, Finland, a project was carried out to connect 18 terraced houses to district heating (Figure C2.1). There were altogether 76 apartments in the housing complex. The system is a secondary 0.6 MPa (heating water) and 1 MPa (hot tap water) system separated by heat exchangers from the primary district heating network. The primary pipeline is built in steel and the secondary network is completely built in PEX.

Technical parameter	
Year of construction	1997 - 1998
Type of Pipe System	Ecoflex
Medium Pipe	PEX and PEX with EVOH
Primary supply temperature	115°C / 70°C
Primary return temperature	45°C / 22°C
Secondary supply temperature	70°C
Secondary return temperature	40°C
Hot tap water temperature	55°C
Circulation pipe temperature	50°C
Total dimensioning power	
• Heating	550 kW (220, 180, 150)
• Hot tap water	740 kW (280, 250, 210)
Total trench length	800 m

Rate of exchange
1 US$ = 5.44 FIM

Description
The buildings are divided in three groups. There was space for heat exchangers in only one building in every group. From the heat exchangers heating water and hot tap water were supplied to the apartments using Ecoflex pipes. To make the installation work easier, Quattro pipes were used as much as possible. Quattro combines 4 medium pipes in one element: two heating pipes, hot tap water pipe and a circulation pipe (Figure C2.2). At the start of the lines the pipe dimensions were so large that the Twin elements had to be used (Figure C2.4). For pipe dimensions used in the total system see pipe table.

Heating water and domestic water were supplied into every apartment using their own pipelines. The Quattro pipelines were brought to some of the apartments in which case the branchings were made in the inspection chamber (Figure C2.5) outside the houses. In this way the joints can be easily checked afterwards in the inspection chambers. There was no room for inspection chambers near some buildings in which case the service connections were made with insulated T-pieces and Twin elements were used. In some of the buildings, the pipes went through the crawl space of the buildings from which the apartment take-offs were taken with the insulated T-pieces. Because some of the pipes were laid under the houses, the total trench length does not correspond to the pipe element length.

Pipe Dimensions		
Ecoflex AquaTwin	28+18/128	50 m
Ecoflex Aqua Twin	32+18/160	40 m
Ecoflex Aqua Twin	40+28/160	110 m
Ecoflex Aqua Twin	50+32/160	80 m
Ecoflex Thermo Twin	2x32/160	90 m
Ecoflex Thermo Twin	2x40/160	30 m
Ecoflex Thermo Twin	2x50/200	160 m
Ecoflex Quattro	2x32/28+18/160	360 m
Ecoflex Quattro	2x32/32+18/160	210 m
Ecoflex Quattro	2x40/40+28/200	160 m

Technical room
The heat exchangers which are installed for the space heating water and domestic hot water were placed in a technical room. In Figure C2.3 shows the piping schematic for the building heat exchangers.

House connections
The pipelines for heating water and domestic hot tap water were brought into every apartment. The space heating loop supplied both steel radiators or fresh air radiators. The hot tap water was further supplied by plastic pipes to the individual taps.

Costs
The Ecoflex pipe distribution system cost 106 500 US$ with the following split:

- Materials 70 %
- Installations 23 %
- Trenching work 7 %

Average Ecoflex pipe distribution system costs per apartment are 1 400 US$. Average Ecoflex pipe distribution system costs per trench metre are 133 US$.

Figure C2.1: Terraced house area

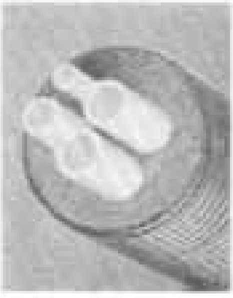


Figure C2.2: Ecoflex Quattro system

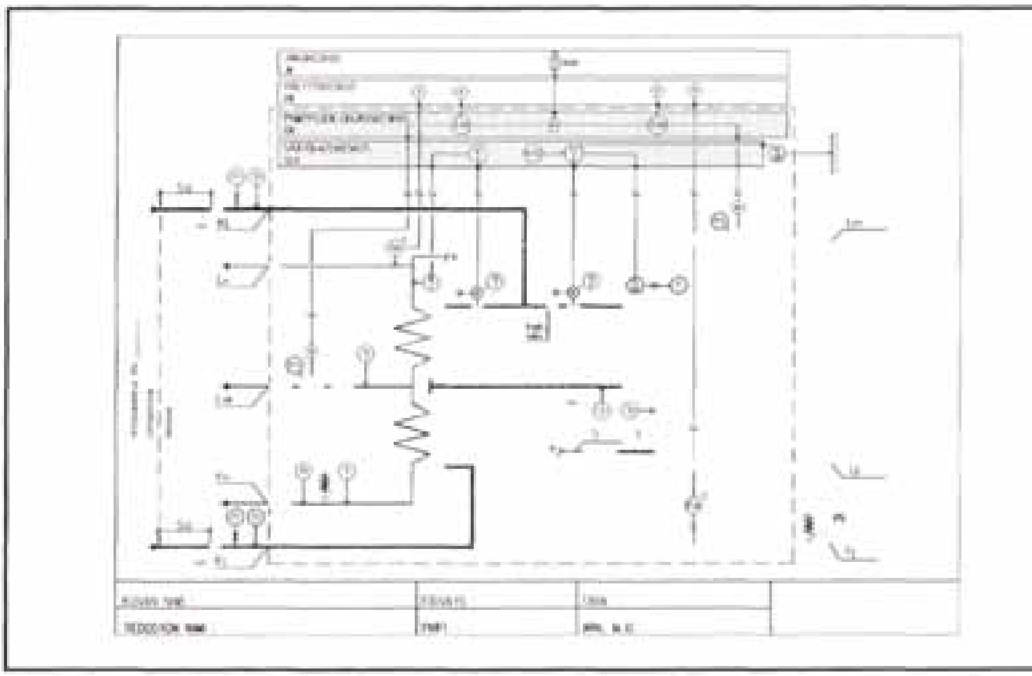
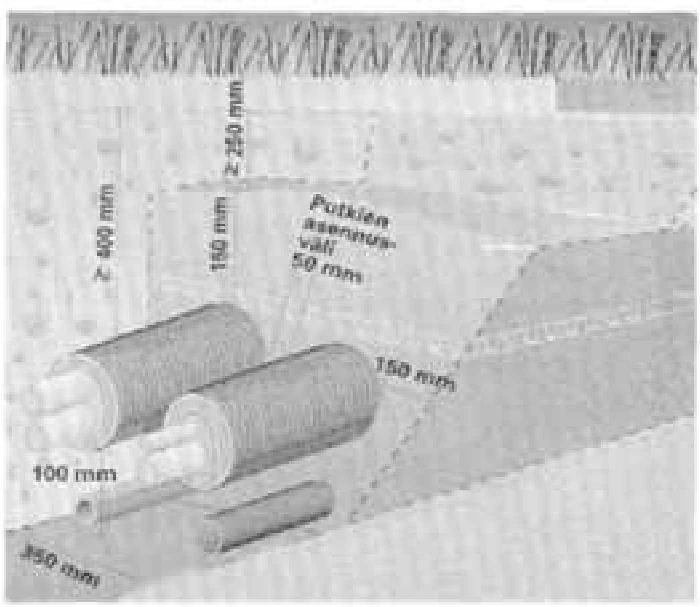


Figure C2.3: Piping Schematic of Building Substation.



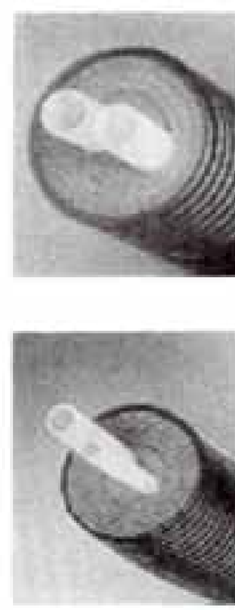
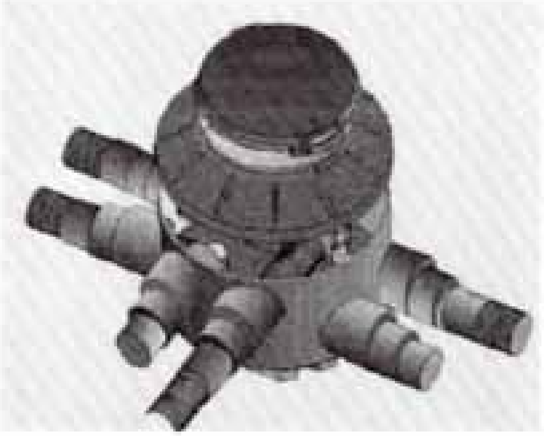


Figure C2.4: Ecoflex Twin system.

Thermo Twin (upper) resp Aqua Twin (lower)



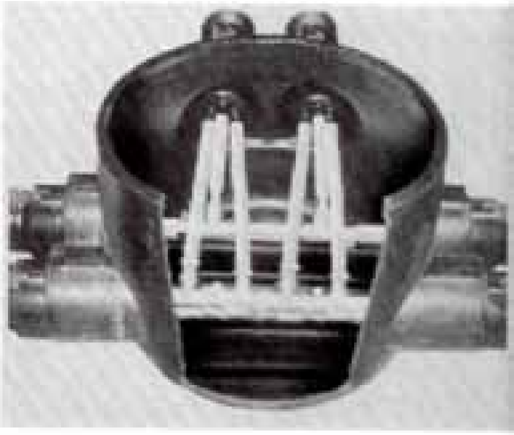


Figure C2.5: Ecoflex inspection chamber

C3 Plastic pipe system in Köln, Germany

1 Introduction

Plastic medium pipes are being used in local district heating systems of GEW - Köln AG. Local district heating systems are being built as secondary pipelines to existing district heating networks or constructed on the basis of gas-fired co-generation plants (CHP) or as CHP - supported district heat supply. The performance of these pipelines is exactly fixed to demand; in comparison, supply with district heat is designed for large areas and for growth. Figure C3.1 shows such a local heating pipeline.

Since most polymer pipelines are only available up to the dimension of 110 x 10 mm and because of the quantity of heat to be transported, it is often necessary to have a mixture of pre-insulated steel (KMR) pipes and plastic medium pipes (PMR). For economic reasons, the application of plastic pipes is limited to smaller pipe diameters at the GEW Köln AG. Cost comparisons have shown that the economic limit is about DN 65. However, the cost comparison should not only concern the material, one has to compare the laying of the complete systems KMR and PMR consisting of pipe building, civil engineering, including the delivery of materials.

2 Planning

To be economic, it is necessary to design the system according to demand as accurately as possible from the very beginning. This requires information on the heat power needed and, if applicable, the characteristics of heat demand, for instance, for hot-water production or air conditioning. In addition, the local situation is decisive for the planned laying technique. In all cases of reconstruction measures in civil engineering and road construction, the ground has to be taken into account. If there is any doubt of the reusability of the excavated material or other problems, then these have to be considered in the contracts, for instance, when land has previously been used for military or industrial purposes. In such cases, PMR should be avoided in favour of KMR.

2.1 Use of PMR

Compared with steel pipes, PMR offers three important advantages. They are easier to assemble, do not require compensators and are not affected by corrosion. There is a calculated margin for determining the limits for the application of PMR-systems, depending on the reserves which one wishes to keep in the design. Taking into account the pipe statics, the range of application considering the information given by the manufacturer should only be restrictively used. Lower loads increase the lifetime.

The systems (PEX and PB) are suitable for use in district heating pipelines for

0,5 (0,6) MPa	overpressure and
90°C	for variable operation.

For this reason, when possible, the forward running temperature at the customer is limited to 85°C. Under these conditions, a similar useful life is expected for PMR and KMR.

Most pipe connections are made with metal connecting elements; the joints are expensive.

2.2 Hydraulic dimensioning of pipelines

The basic data for dimensioning are the prescribed quantities of heat with the required temperature distribution. In addition, for the hydraulic layout, it has to be decided whether the supply should be operated directly or indirectly. The first dimensioning of the required pipeline diameter can be done with the information provided by the manufacturer. Boundary conditions are usually:

Flow velocity in the pipelines	< 2 m/s
Total pressure loss (dyn.+ stat.)	< 0.5 MPa

For Köln, the economic area for flow velocities lies between 1.4 m/s and 1.6 m/s.

For reasons of cost, armatures are fitted sparingly and only at strategically important places, and only in the case of a mixed design of PMR and KMR. Otherwise, fittings are only used at transfer stations.

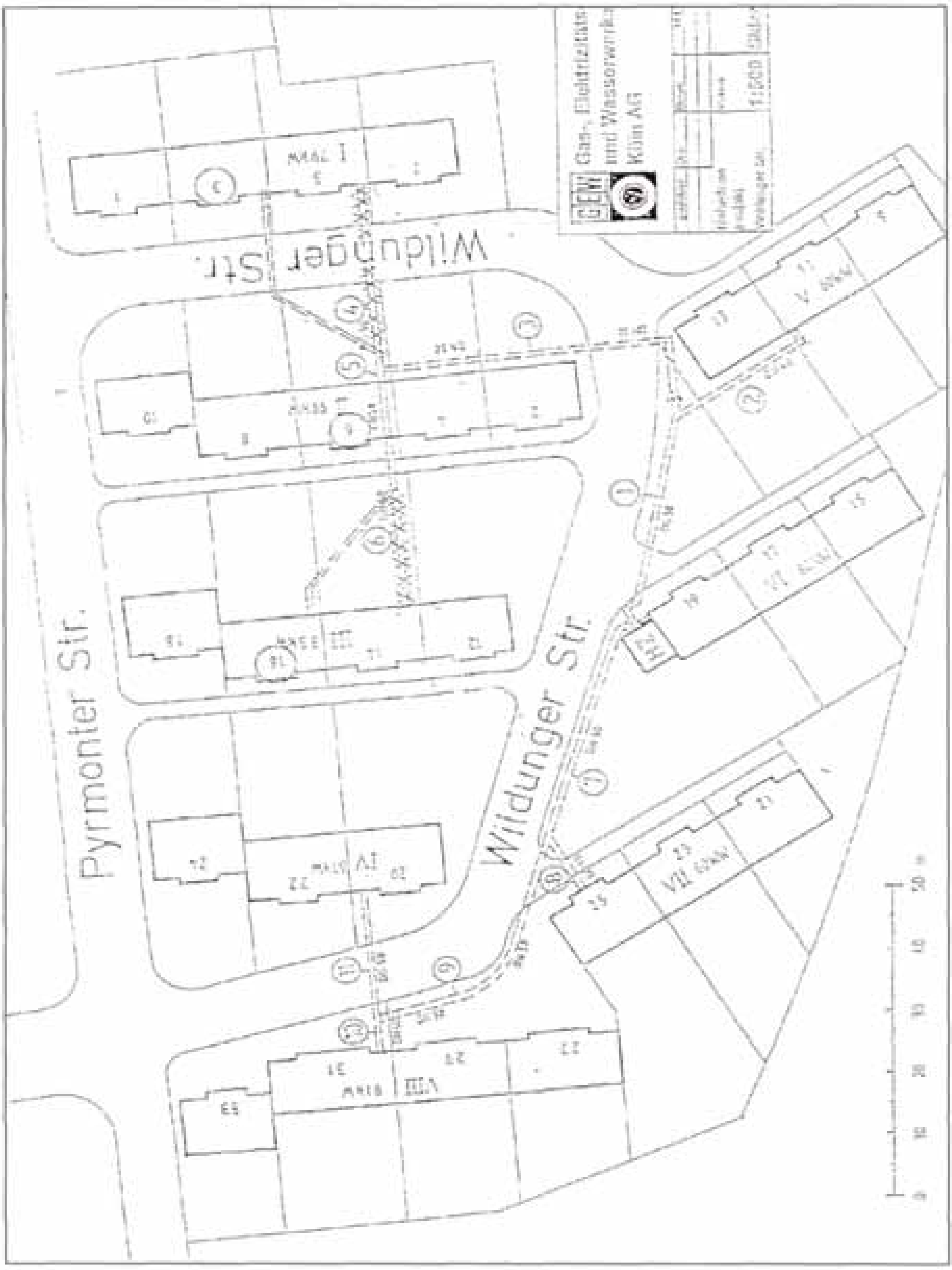


Figure C3.1: Local district heating systems of GEW, Köln.

Heat generation and heat distribution are separated. To design the pumps, which are found in the generating station, a pipeline characteristic should be worked out. It is not always sufficient to select pumps only according the peak values. The last adaptation of the hydraulic design usually occurs very late, often only after start of construction.

2.3 *Selection of route*

To decide the engineering measures, it is necessary for all those involved in the work to inspect the building site. Routing the pipeline away from consolidated paths, and public roads for traffic is usually cheaper and allows the work to be undertaken more quickly. It can also be more favourable to take a short cut from house to house through the cellars.

Later changes to the routing of pipelines can be carried out immediately with flexible systems on the building site. Avoiding barriers can be undertaken without any problem, similarly a necessary change from pipes laid side-by-side to one-above-the-other can easily be undertaken. A proof of the statics is not required as compensation for changes in the length of PMR caused by temperature is not needed.

In addition to the methods for connecting branches for instance, for house connections using tees in the supply pipeline, connections can also be looped in. These can be the cheaper solution in spite of a longer laying length.

2.4 *Announcements and placing orders for construction work*

The tenders are usually all-inclusive. The offer is then based on the price per running meter or per piece. Characteristics of the building site are described as accurately as possible and explained on the occasion of the site inspection. This helps the contractor to reduce calculation risks.

Pipeline trenches defined as "trenches, not to be trodden on" according to DIN 4124 are made up to 1.25 m deep. Substitution of soil (outside the pipeline zone) is only allowed after appropriate notification.

GEW-Köln AG as customer provides all the necessary material.

Details of the construction project, system to be laid, the qualifications of the contractor including possible subcontractors, the personnel carrying out the work, the necessary quality of construction and the certification / tests etc. are discussed during negotiations of the contract.

Pipe and sleeve connections are carried out by assembly personnel, instructed by the manufacturers of the system. They must have had sufficient practice with the products being used. The GEW Köln AG organisation responsible for quality control has showed that a one-day training period is not sufficient.

The warranty period amounts to five years and includes all direct and indirect applications originating from the case under warranty.

3 Execution of the engineering

Pipe material, rolled onto drums of different prefabricated quality, is delivered directly to the building site. The number of joints is reduced as a result of laying exact lengths of pipe. A clear cutting plan for the material is important, to reduce waste lengths to a minimum.

As a result of the flexibility of the pipe material it is possible to use a technique similar to laying cables. Small, manoeuvrable construction equipment has proved to be particularly favourable. It is especially advantageous if the contractor can undertake both the underground engineering and pipe-laying as well as the assembly of pipe connections.

Press-on connections are expensive and to some extent a longer delivery time for the material has to be calculated. It is practical if the connecting elements can be supplied as a complete set in a welded plastic bag. As a result of delivery times it has proved advantageous to keep some material in reserve.

For district heat pipelines laid in the ground, only inseparable, form-locking connections can be permitted. Only metallic pipe connections should be used, tested according to the DVGW-Arbeitsblatt W 532. The medium-pipe connection of a particular brand usually requires company-specific tools. The suppliers of the system are normally prepared to make the pressing tools available free-of-charge.

The time required for the construction work is normally determined by the ground works, as the system used means that only a small effort is required for assembly of PMR. As a result of the fast laying process for longer lengths of pipe and the immediate filling-in and closing the pipe trench - with the exception of the area around of pipe connections - steel bridges for vehicles and pedestrians are not needed and expenditures and efforts for building site equipment, barricades, traffic diversions etc. are reduced.

The laying of smaller nominal diameters can be undertaken by the assembly workers without the support of machines. For larger nominal diameters and longer pipe sections it is recommended using suitable unrolling equipment (cable trolley).

The production of pipe connections for smaller nominal diameters can be carried out more efficiently by one single worker. In this case, cooling times for shrinking sleeves or waiting times for foaming can be favourably integrated into the flow of work. In the laying and production of pipe joints of medium and larger nominal diameters, an auxiliary helper should be used to align and fix the medium pipe. Difficulties are encountered when the pipe material relaxes during laying.

For surrounding temperatures near or below freezing point, the PMR **must** be preheated for laying, so that a sufficient flexibility is present. This can be done, for instance, by storing the pipes in a heated warehouse or by heating with a hot air blower.

If pipes have to be cut, for instance in the case of a repair, then the pipeline must be fixed. The shrinking of the medium pipe as a result of cooling down must be controlled with suitable tools. If necessary, an adjusting piece must be fitted.

Before refilling the pipe trench, the laid PMR has to be checked visually for tightness at medium pipe joints using a pressurised air test (**dust- and oil-free air** with 20 - 30 kPa overpressure).

For hilly areas, a watertight sectionizing of the individual pipe lengths is recommended at the connections, e.g. using the end-cap techniques commonly used in KMR systems.

For repairs and extending the pipeline, there are squeezing processes for PE-HD pipelines known from gas and water supply pipelines. Squeezing means the provisional closing of a pipeline with a suitable clamping tool when no shut-off valves are available. In this way, during the operation of the pipeline, a connecting branch pipeline can be added or repairs undertaken without shutting down the whole line. Following investigations in Köln this process showed no reduction in the service life. However, reliable long term experiences from the squeezing technique are not available.

After entering the house, at the end point of the PMR-systems, defined fixed points are to be made. Pipe ends are closed with end plugs. The forward and return pipelines should be **distinctly** marked.

4 Pipeline operation

The pipelines are filled with prepared water (condensate). The water quantity is controlled automatically. By means of the installation of a filter plant in a secondary line, particles and other contaminants are filtered out from the hot-water circuit. All lines are monitored by remote control, both generation as well as customer systems.

Pipelines operated by GEW-Köln AG, function under very different operating conditions reliably and without problems. Problems only occur as a result of external influences.

5 Costs

PMR have a different cost structure than KMR. Civil engineering is cheaper since the trench profile is smaller. As a result of the flexibility of the pipe material, costly route situations can be avoided. The easy-to-assemble PMR-system, which usually comes to the building site as continuous lengths of material, produce clearly reduced assembly costs. In contrast to KMR-pipelines there is no need to weld the steel pipe lengths. The PMR-pipelines are normally cut to the right lengths. Although the sleeve technology for joining the jacket pipes is identical, a considerably reduced number of sleeve joints is required.

From the point of view of the utilities, today's price for PMR does not seem to be acceptable. In individual projects it was determined through recalculations that today PMR (material with appertaining fittings - without assembly) is overpriced compared to KMR. Small nominal diameters were ca. 70% and larger nominal diameters ca. 50% more expensive. PMR will only have a chance in the future, if it can be offered at the same price level as KMR. After all, the utilities have additional expenditures to compensate for the limited temperature and pressure parameters.

For the Köln area, the present construction costs amount to ca. 175 $/m for PMR up to DN 40 and about 225 to 265 $/m for sizes up to DN 65. A strong synergy effect to reduce costs can be found in the simultaneous laying of gas, water, electricity and telecommunications pipelines and cables. This type of co-ordinated construction is also very highly appreciated by the general public.

The author of this contribution is:
Dipl. Ing. Wolfgang Peter, GEW-Köln AG.

C4 Standards

Document Title	Document No	Developing Organization Adopting Bod
The following plastic pipe standard system is under development and is by May 1998 published as Draft International Standard, DIS.		
Plastic piping systems for hot and cold water – Polypropylene (PP)	ISO/DIS 15874	ISO
Plastic piping systems for hot and cold water – Crosslinked polethylene (PE-X)	ISO/DIS 15875	ISO
Plastic piping systems for hot and cold water – Polybutylene (PB)	ISO/DIS 15876	ISO
Part 1: General Part 2: Pipes Part 3: Fittings Part 5: Fitness for purpose of the system Part 7: Assessment of conformity		
Further standards of interest		
Thermoplastics piping systems – End-load bearing mechanical joints between pressure pipes and fittings – Test method for resistance to pull-out under constant longitudinal force	EN 712:1996	ISO
Plastics piping systems - Thermoplastics pipes - Determination of resistance to internal pressure at constant temperature	EN 921:1996	ISO
Plastics piping systems for the transport of water intended for human consumption – Migration assessment	EN 852:1996	ISO
Influence of materials on water intended for human consumption – Organic materials – Pipes, fittings and their coatings used in piping systems. Odour and flavour assessment of water	EN 1420:1996	ISO
Plastics piping systems for the transport of water intended for human consumption – Migration assessment	EN 852:1996	ISO
Influence of materials on water intended for human consumption – Organic materials – Pipes, fittings and their coatings used in piping systems. Odour and flavour assessment of water	EN 1420:1996	ISO

Document Title	Document No	Developing Organization Adopting Bod
Plastics piping systems – Plastics pipes and fittings - Measurement of dimensions and visual inspection of surfaces	EN 496	ISO
Plastics piping systems – Plastics pipes and fittings – Determination of the opacity	EN 578	ISO
Elastomeric seals – Materials requirements for pipe joint seals used in water and drainage applications – Part 1: Vulcanised rubber	EN 681-1	ISO
Plastics piping and ducting systems – Injection moulded fittings – Test method for visually assessing effects of heating	EN 763	ISO
Plastics piping systems Thermoplastics pipes – Determination of resistance to internal pressure at constant temperatures	EN 921	ISO
Copper and copper alloys – Plumbing fittings – Part 3: Fittings with compression ends for use with plastic pipes.	EN 1254-3	ISO
Plastics – Determination of the melt flow rate of thermoplastics	ISO 1133:1991	ISO
Plastics – Determination of water absorption (Item No 16H)	ISO/FDIS 62:1997	ISO
Preinsulated flexible pipe systems: Requirements and tests	PREN XXXX:1998 (CEN/TC 107/WG 10 N 65 D)	CEN
Plastic piping systems – Crosslinked polyethylen (PE-X) pipes – Determination of degree of cross-linking by solvent extraction	SS-EN 579:1997	SIS
Plastic piping systems – Thermoplastics pipes – Determination of resistance to internal pressure at constant temperature	SS-EN 921:1995	SIS
Plastic piping and ducting systems –Thermo plastics pipes – Determination of the longitudinal reversion	SS-EN 743:1997	SIS
Rohrleitungen aus Kunststoffen für Warmwasser-Fussbodenheizungen; Allgemeine Anforderungen	DIN 4726:1993.09	DIN
Rohrleitungen aus Polybuten für Warmwasser-Fussbodenheizungen; Besondere Anforderungen und Prüfung	DIN 4727:1988.09	DIN

Document Title	Document No	Developing Organization Adopting Bod
Rohrleitungen aus vernetztem Polyethylen hoher Dichte für Warmwasser-Fussbodenheizungen; Besondere Anforderungen und Prüfung	DIN 4729:1993.09	DIN
Rohre aus vernetztem Polyethylen (VPE); Allgemeine Güteanforderungen, Prüfung	DIN 16892:1985.03	DIN
Rohre aus vernetztem Polyethylen (PE-X); Masse	DIN 16893:1988.11	DIN
Rohre aus Polybuten (PB) – Allgemeine Qualitätsanforderungen und Prüfung	DIN 16968:1996.12	DIN
Rohre aus Polybuten (PB) – PB 125 – Masse	DIN 16969:1997.12	DIN

IEA District Heating and Cooling

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1999:T6
ISBN 90-5748-005-0