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Sektion 6 a

Heat distribution – pipe properties

Stability of PUR insulation in pipes for heat- and refrigeration-transmission

M. Gietzelt, T. Grage, M. Kahle,
Fernwärme-Forschungsinstitut Hannover e.V., Hannover/Germany

Stability of PUR insulation in pipes for heat- and refrigeration-transmission

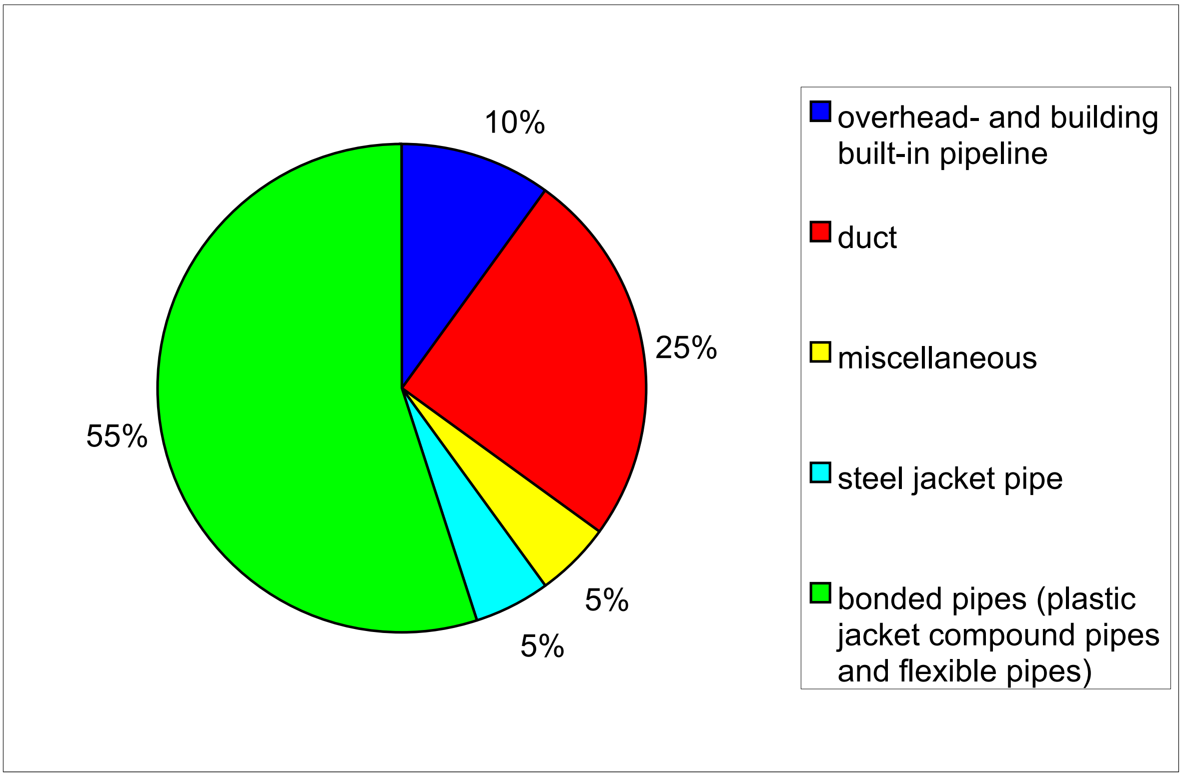
Prof. Dr.-Ing. M. Gietzelt, Dipl.-Ing. T. Grage, Dipl.-Ing. M. Kahle

Fernwärme-Forschungsinstitut in Hannover e.V., Max-von-Laue-Str. 23, 30966 Hemmingen, +49 (0) 511 94 37 0, ffi@fernwaerme.de. www.fernwaerme.de

1 Motivation for examining the life time span

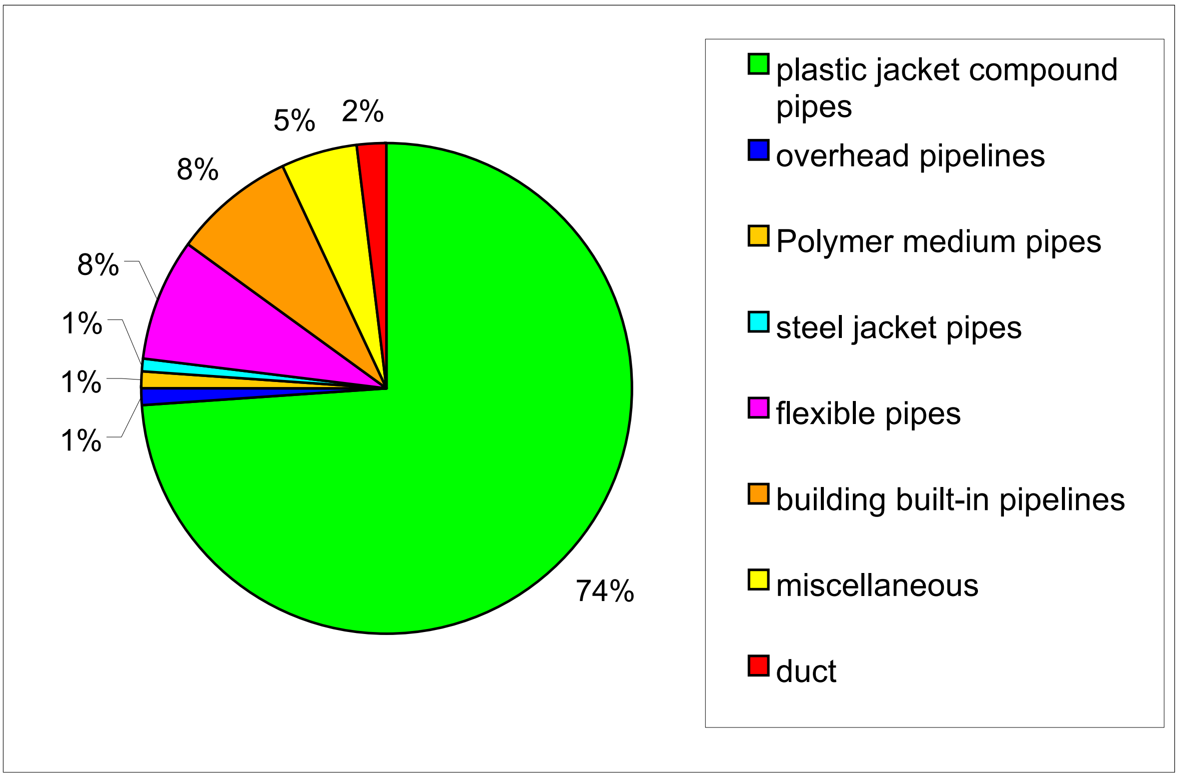
At present a great part of district heating and cooling pipes are insulated with Polyurethane foams. Polyurethane foams are characterised by high mechanical strength, low thermal conductivity, good flexibility in respect of application and high ageing stability. Because of the varying characteristic features of Polyurethane foam it can be applied for different heat and cooling applications.

Picture 1: *Over view about the laying methods (blue: application of Polyurethane with cooling pipes; red: application of Polyurethane with heating pipes)*



Picture 2: *Proportion of the laying of all district heating pipes in the Federal Republic of Germany [1]*

For new pipelines in district heating earth-laid plastic bonded pipes (KMR) and flexible pipelines with polyurethane insulation are mainly used.



Picture 3: *Distribution of the length of pipe lines built in the Federal Republic of Germany of district heating water pipes in the year 2004. [1]*

For the time being district cooling pipes with polyurethane insulation are mostly laid in buildings. Amongst others the industry has the intention to use PUR insulated pipes from the district heating sector for cooling purposes in the future.

District heating pipes are planned with a life span of minimum 30 years today (DIN EN 253: minimum 30 years; VDI 2067:2000: 40 years). The economics calculation for cooling pipes amounts to a minimum life span of 20 years (VDI 2067:2000). The mechanical resistance throughout the whole operation time is decisive for the technical life span. For the economical life span the heat conductivity is most important because this governs the heat loss of the pipeline.
In order to acquire an economical and technical safe operation it is necessary to determine the influences on ageing and the stages of ageing. There are numerous rules with minimal requirements to be kept for new district heating and cooling pipes for the purpose to safeguard the life span. In Germany the following regulations have to be observed:

Laws	EC directive and regulations, national laws and regulations,...
Standards	ISO, EN, DIN,...
Guidelines	AGFW, VDE, VDI,...
Work sheets	VDI, DVGW, AGFW,...

Table 1 *Overview to the useable comprehensive body of legislation at PUR-isolated bonded pipes*

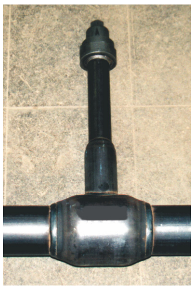
At present, the national standardisation is generally followed with the exception of earth laid, hot going plastic bonded pipes, which will be discussed more thoroughly later on.

For the earth laid, hot going plastic bonded pipes, European standards have to be observed (for flexible Polymer cover pipes (PMR) the relevant standards will soon be made known):

EN 253: Preinsulated bonded pipe systems for directly buried hot water networks - Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene [2]

EN 448: Preinsulated bonded pipe systems for directly buried hot water networks - Fitting assemblies of steel service pipes, polyurethane thermal insulation and outer casing of polyethylene [3]

EN 488: Preinsulated bonded pipe systems for directly buried hot water networks - Steel valve assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene [4]



EN 489: Preinsulated bonded pipe systems for directly buried hot water networks - Joint assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene [5]

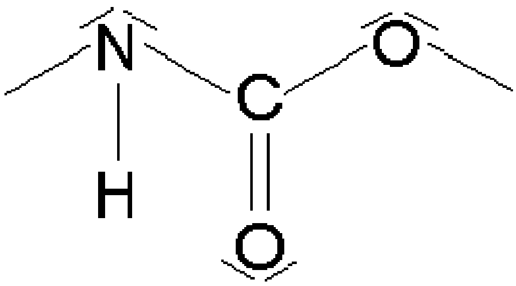
These standards specify the following requirements:

- mechanical qualities
- chemical qualities
- heat conductivity
- other technical requirements for pipeline construction systems

In the event that plastic bonded pipes are used in a cooling distribution system, the international standard for insulation of cooling pipes ISO 15758 as well as the VDI guidelines 2055 are applied. When - in special cases - steam pipelines with PUR insulation are built, the standard and the technical guidelines of the European Union 97/23EG (Pressure Equipment Directive) must be observed.

2 Basic factors of Polyurethane foams

Polyurethanes are polymers which show several groups of carbamic acid and who have on the right oxygen atom further atomic connections.



Picture 4: *Structure of the carbamic acid group*

Polyurethanes are produced in a polyaddition of polyols (organic compounds with many OH-groups) and isocyanats (organic compounds with NCO-groups, in the majority of cases bifunctional isocyanats = Di-isocyanats) mostly.
The most important raw materials of polyurethane production are mineral salt, coal, crude oil, beet sugar or cane sugar, corn and fats. The isocyanates may be aromatic (organic compounds, which accords to the aromaticity criterias) or aliphatic (organic compounds which are not aromatic), whereby aromatic isocyanates are more commonly used than aliphatic.

The reaction of polyole and isocyanate appears step by step. Urethane and urea emerge as a by product of the manufacture of polyurethane. These are important for the cross-link of the polyurethane molecules.

Apart from the direct reaction of polyole with isocyanate it is possible to process polyole to polyetherpolyole. At the base catalysed reaction of two - and polyvalent start alcohol with epoxides the polyetherpolyols emerge. In special cases some different substances are used instead of polyols. This variation of the reaction channels and the reaction partners gives room to a great variation in the qualities of the polyurethane. To simplify matters we speak now only of polyole and isocyanate.
Apart from the basic components, several further substances are used for the manufacture of polyurethane foams:

- Catalyser : i.e. amine, organotin compound
- Tenside
- Foam stabiliser: i.e. silicon-organic compound
- Flame protection: i.e. aluminium oxide hydrate, ammonium polyphosphate, chlorine-, bromine-, phosphorus- nitric-organic-compounds
- Filling agents: i.e. carbon black, chalk, silicates, barytes, glass fibres
- Ageing inhibition
- Colorant
- Antistatics: i.e. organic ammonium connection
- Biocide
- Separating agents: i.e. wax, silicone, metal soaps
- Blowing agents

All components, except for the nucleating agents, are in liquid form, gas form or dissolved for the manufacture of the polyurethane foam. The nucleating agent can also be a disperse particulate material. Because the blowing agents have a great influence on the qualities of the polyurethane foam we would like to go into more detail.
Different methods can be used to place the blowing agents into the foam:

- Release of propellant by chemical reaction: The blowing agent is mixed with one of the basic components – mostly polyol -. The blowing agent decomposes thermally at the reaction of polyol and isocyanat or it reacts with one of the other components of the mixture. One example is the reaction of water with isocyanat when released from carbon dioxide.

- Release of propellant by physical process: The propellants are dissolved or in liquid form. In case of liquid propellants they evaporate because of high temperature at the reaction of the basic components. For this kind of propellant generation the blowing agents may be FCKW and cyclopentan. In order to release dissolved blowing agents the pressure must be lowered. This principle applies for the manufacture of vacuum insulation material.

- To place the propellant by mechanical process: The propellant is either dispersed in a reaction mixture or it has to be compressed injected into the reaction mixture. Therefor carbon dioxide may be used for example.

In many cases several different methods of releasing the propellant with different blowing agents are used.
The pipe manufacturer aim at reducing the heat conductivity as the strength is constant. The cell diameter is one factor. At the PUR-foam production the choice of the blowing agent and other additives and contribution will not only appropriate the

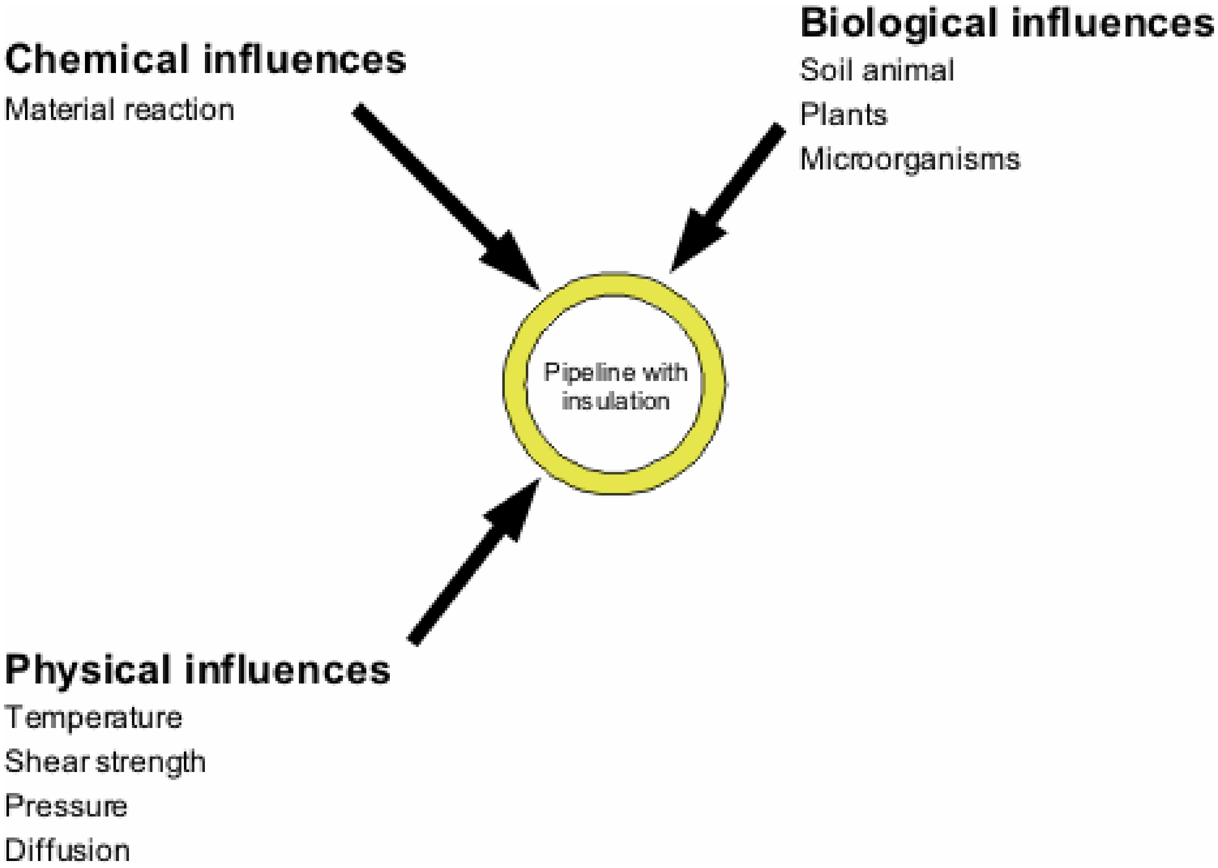
cell gas heat conductivity and the deterioration. This choice appropriates the cell structure too. A reduction of the cell diameter, where is no convection in current foams, means a decrease of radiation heat conductivity. Some micro-foams are available with cell diameters under 0,1 mm. Will the cells being much smaller – to the extent that the cell diameter will be smaller than the mean free path of the gas molecules – the gas heat conductivity will get near zero. These foams with very low gas and radiation heat conductivity are called nanoporous foams. It is expected that the deterioration of these foams will be slower than topical foams because there will be no diffusion like the solution-diffusion-model but like the much slower Knudsen Diffusion [7]. With the reduction of the cell diameter the strength will decrease while the density will be equal. Should the strength be constant the density must increase. For example, by increasing the actually required density of 60 kg/m³ to 100 kg/m³ the heat conductivity will raise to only about 6% at CO_2 blown foam [6]. Regarding the interconnection features – as well at the steel medium pipe or the PE-X medium pipe as at PE-jacket pipe - there are no cognitions. To the tangential shear strength there is also no data available. The cell diameter can be influenced by the basic components – polyols and isocyanats – to a minor degree. A much bigger influence have the blowing agents, nucleating agents, foam stabiliser and surface active substances as well as the phase, the concentration and the allocation [6].

3 Variation of the heat conductivity and density

As mentioned before, the operation ability and the economic efficiency of the heating or the cooling net should be guaranteed for the total projected operation period in spite of operational influences or outside influences. Therefore the following has to be observed:

- Preservation of the mechanical stability under the influence of thermo-mechanical loads
- Prevention of water penetration and humidity into the foam
- Maintaining a low heat conductivity

The topic changes of polyurethane foam properties at pipes is very extensive. Therefore only the most important effects will be presented in the following chapters.



Picture 5: *Overview of the influences on insulated pipes*

3.1 Influence

3.1.1 Biological influence

Biological influences happen because of animals, plants and micro organisms like bacteria and fungus. In principle it is possible that biological factors influence the resistance and heat conductivity of heat- and cooling pipes. Until recently, no great attention has been paid to the biological influences of preinsulated PUR-foam directly buried pipes.

3.1.2 Chemical influences

Chemical influences are all reactions of and with the polyurethane insulation material. According to the stand of the technique the validity of the Arrhenius law is applied for the ageing of Polyurethane insulation materials.

$$k = A \cdot e^{\frac{-E_a}{RT}} \quad (1)$$

k — *reaction rate*
A — *frequency factor*
E_a — *activating energy*
R — *gas constant*
T — *absolute temperature*

The hydrolyse is one of the most important chemical reaction during usage of PUR insulation with warm going pipes. Conditions for the hydrolyse are humidity in the foam as well as temperatures of more than 50°C [8]. Big changes in foam caused by hydrolyse are noted for temperatures over 100 °C (373,15 K) [9]. With the hydrolyse the foam decomposes itself under the influence of water in shorter chemical compounds.

In the past R11 and other FCKW blowing agents were used. These split under thermic load chlorine and flour atoms, which, as free radicals, are creating new connections including polyurethane molecules. The reaction of polyurethane molecules with free radicals lead - just like the hydrolyse - to the destruction of the cell walls. The mechanical strength is hereby reduced and the effective diffusion coefficient and the heat conductivity of the foam is increased. Reactions of CO_2 are yet unknown in polyurethane foams.

The reaction of polyole and isocyanate and the additives is never really complete during the manufacture. For this reason numerous reactions take place during operation between the basic materials, within the basic materials and other additives as well as diffused in gases and liquids. Because of this the properties of the polyurethane foam can change to the positive or to the negative. All reactions in the polyurethane foam are influenced by catalysts which are added during manufacture.

3.1.3 Physical influences

3.1.3.1 Temperature

The absolute temperature and the changes in the temperature influence the mechanical as well as the thermal quality of the PUR insulation in different ways. As said before, the absolute temperature governs the reaction rate. Furthermore, the temperature inside the insulation is decisive for the condensation of water and blowing agents - this is especially the case with cold going pipes – and the evaporation of the liquid blowing agent and water – especially with warm going pipes. According to the standard of technique to date, temperature introduces to the general observation of the ageing and the changes of the mechanical properties of the polyurethane insulation materials of pipelines by the Arrhenius equation. If the change of heat conductivity is in the focus of the analysis, the Temperature will be introduced to gas and radiation heat conductivity. However, the change of gas and radiation heat conductivity are reversible.

The heat conductivity influences the diffusion coefficients and the diffusion flow too. The temperature is not equal to the radius. Through this a partial pressure difference results in the foam, so Fick's diffusion of cell gas out of the jacket is accelerated at hot going pipes and the input of air and water is reduced. At cold going pipes the effect is reversed – into the foam the Fick diffusion flow of air and water raises and the diffusion flow of the propellants decreases. Additionally thermal diffusion is caused by the temperature gradient in the foam. At hot going pipes the thermal-diffusion results in a flow of the over average heavy propellants (i.g. CO_2: M ≈ 44u; C_5H_{10} ≈ 70 u, [10]) from the medium pipe to the jacket pipe. The thermal-diffusion flow of the air molecules are inverted because of the under average molecular weight (N_2: M ≈ 28 u; O_2 ≈ 32 u, [10]). At cold going pipes the diffusion direction is inverted.

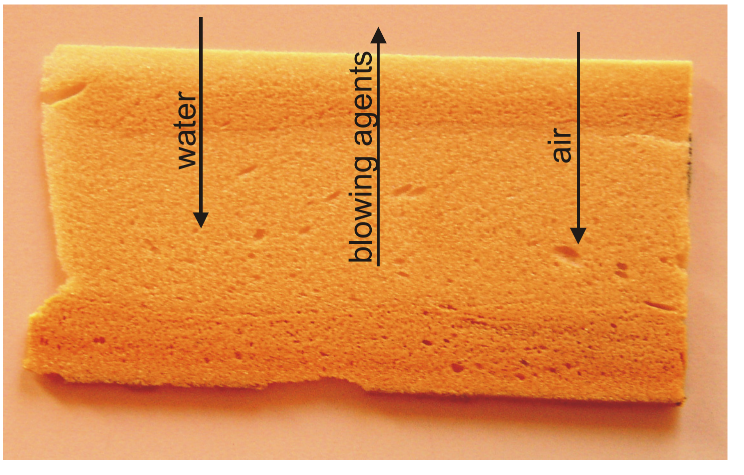
Changing temperatures influence the life time span and the properties of the PUR-isolation. They are not considered in the lifetime calculation at the actual state-of-the-art of science and technology.

Not only the partial pressures of gases and fluids change with the temperature but also the volumes of the solids in the PUR-isolated bonded pipes change. Because of the external pressure – at polymer medium pipes the medium pressure too - and multiple expansion coefficients the expansion is hampered. Stresses appear.

3.1.3.2 Stresses

The stresses in the isolation are in axial, radial and tangential destination. The axial stresses are mostly caused by the spatiotemporal different thermal expansion. Twisting of the pipes while under construction or a one sided load determines tangential stresses. Radial stresses are caused by thermal expansion as well as by the mass weight of the medium pipe, which the PUR-isolation carries.

3.1.3.3 Diffusion



At normal use there are only two mass flow mechanisms in the PUR-isolation of pipes:

- Fick's diffusion: The mass flow is caused by a concentration or a partial pressure difference. With higher partial pressure or concentration differences the diffusion flow grows.
- Sorret's diffusion: The mass flow happens through different temperatures. With raising temperature gradients the thermal-diffusion grows. But raising temperature lowers the diffusion flow. Looking at the whole diffusion flow within the foam of pipes one can observe that thermo-diffusion is not as powerful as Fick's diffusion. All known described mass flow in foams do not consider thermal diffusion.

Both mass transport processes are spatiotemporal unsteady. Besides the diffusion is over phase interfaces. This makes a calculation of diffusion flow in the foams different. Furthermore the various materials of a bonded pipe have extreme different diffusion coefficients and permeation coefficients.

Gas	D_{eff} [10^{-13} m²/s] for PUR-foam 20°C	50°C	60°C	70°C	P [10^{-16} mol/(msPa)] PUR-foam 23°C	50°C	PE-jacket pipe 5°C	23°C	40°C
N_2	25	130	220	-	10	47	0,24	0,65	1,6
O_2	150	470	650	-	61	165	0,9	1,9	4,9
CO_2	500	1000	1300	-	230	3500	5,1	8,6	19
c-pentan	0,6	5	7	-	0,5	1,7	-	23	-
R11	0,06 ... 5,7	-	-	3,3	-	-	-	-	-

Table 2 *Diffusion and permeation coefficients of different gases in PUR-foam and PE-jacket pipes [11]*

- steel / copper / aluminium: In metals is nearly no diffusion. In good approximation metals are hermetically diffusion sealed.
- HD-PE / X – PE: Steam and air diffusion are highly constricted. The diffusion of cyclopentan is comparatively lowly constricted.
- PUR-foam: Air, water and several propellants have high diffusion coefficients. The propellant cyclopentan can badly diffuse in PUR-foam.

3.2 Calculation models

3.2.1 Heat conductivity

For the heat conductivity the following equation may be given:

$$\lambda = \lambda_{conv} + \lambda_{cond} + \lambda_{solid} + \lambda_{rad} \quad (2)$$

λ_{conv}	*convection thermal conductivity*
λ_{cond}	*gas thermal conductivity*
λ_{solid}	*solid thermal conductivity*
λ_{rad}	*radiation thermal conductivity*

During service life the heat conductivity changes. For the general correlation of heat conductivity alteration

$$\lambda(t) = f(A, B, C, ...) \quad (3)$$

(A,B,C etc. are the influence coefficients) some different mathematical methods have been designed.

- Kai-Erhard Wagner: Within the scope of his dissertation he created a simulation for alteration of heat conductivity of polyurethane foams. He used a cubic cell model for the mathematical-physical determination of the heat conductivity of polyurethane foam plates. In difference to the other known methods his basic approach provides condensation and small deformation of the cells in the PUR-foam. [12]

- The IEA announced under the title “How cellular gas influence insulation properties of district heating pipes and the competitiveness of district energy” their own calculation method for determination of heat conductivity within district heating pipes over the lifetime. This method is based on a mixture of physical laws and constants determined by statistical procedures. [13]

– An analysis for heat conductivity, created by the IMA at the research project “”Advanced PUR-isolation of district heating pipes” Subtask physical-mathematical modelling of PUR-foam layers and experimental analysis of thermo-mechanical long-term behaviour of foam patterns and preinsulated bonded pipes” (““Verbesserte Polyurethan-Wärmedämmung von Fernwärmeleitungen“ Teilaufgabe Physikalisch-mathematische Modellierung von PUR-Dämmschichten und experimentelle Untersuchungen zum thermomechanischen Langzeitverhalten von Schaumstoffmustern und Kunststoffmantelrohren“ [11]), is like the calculation method of the IEA solved by Bessel equations. But this does not use statistical values and correlation.

– The mathematically easiest of all methods for determining heat conductivity changes in PUR-isolated pipes shown here, has been created by the Fernwärme-Forschungsinstitut Hannover e.V. It is fully based on statistical values [9].

All methods are limited real-world solutions. Because sufficient data is not available for determining the constants and verifying the methods extensive numeric design engineering is necessary in order to determine explicit values. Also every basic approach for the determination of heat conductivity changes may be used for special cases only. Until now no scientific method is known which demonstrates its universality.

3.2.2 Strength

No equation like that for heat conductivity in foams exists for the static strength. The change of the axial shear strength could be written:

$$\tau_{ax} = f(a_1, b_1, c_1, ...) \quad (4)$$

For compression strength in radial destination a general equation could be demonstrated:

$$\tau_{rad} = f(a_2, b_2, c_2, ...) \quad (5)$$

(a1,b1,1 etc. are the influence coefficients)

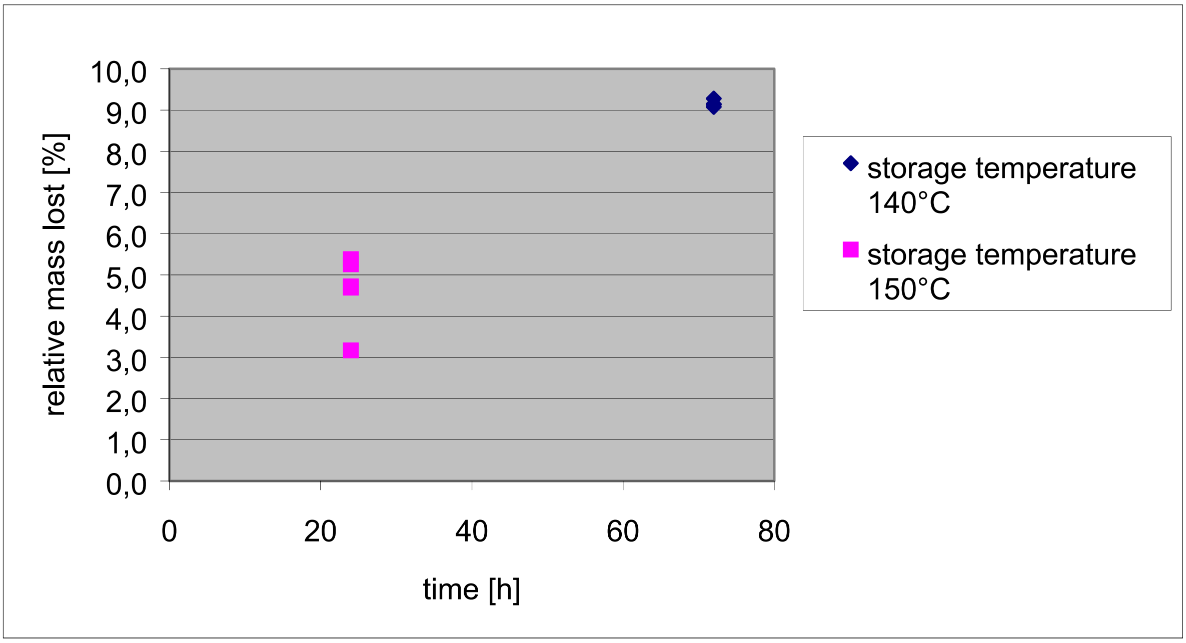
Not many statements in respect to change of mechanical properties of PUR-isolation at pipes can be found in the available literature. In EN 253:2006-02 the Arrhenius equation is used for a correlation between the continuous operation temperature and the reduction of mechanical strength. Other influences are not yet incorporated.

3.3 Readings and trials

During the last years some research projects revealed how several influences act on property changes. Most research projects worked with artificially aged pipes. An important exception is the research project “Thermal history of PUR-foams at practice aged preinsulated bonded pipe systems in terms of heat conductivity and strength” (“Zeitstandsverhalten von PUR-Schäumen in praxisgealterten Kunststoffmantelrohren hinsichtlich Wärmeleitfähigkeit und Festigkeit” [11]). In this research project more than one hundred natural aged district heating pipes were tested for thermal and mechanical properties.

No data are available about long-term changes of heat conductivity and strength depending on operating temperatures. As aforementioned the operation temperature influences the diffusion processes, condensation and evaporation as far as chemical reactions are concerned. Furthermore it is known that the formation of a layer of ice in pipelines’ PUR-foam with medium temperature below 0°C (273,15K) hampers the intrusion of more water to the foam. So the raise of heat conductivity is limited [14]. The shown effects can not be quantitatively evaluated for the time being.

At the Fernwärme-Forschungsinstitut trials for deterioration of district heating pipes have been started. One of the trials included a hydrolysis[1] trial in a closed container.



***Picture 6** Mass lost in dependency of time at a hydrolyse trial of PUR-foam. [9]*

Hydrolyse results in the destruction of the membranes of the cells and partition walls. This is shown by the mass lost. For the allocation of measurement in picture 6 probably used catalyses are responsible. At production of PUR-foams tertiary amines, cyclic or aliphatic aminoether, cyclic or aliphatic aminidine as well as metal organic compounds are mostly used. They are signed by heavy temperature appending behaviour. Including the collapse above the substance specific category temperature. Another possible reason is the water pressure. The probes were heated in hermetically closed containers at trial temperature, so different pressures had been applied. [9]

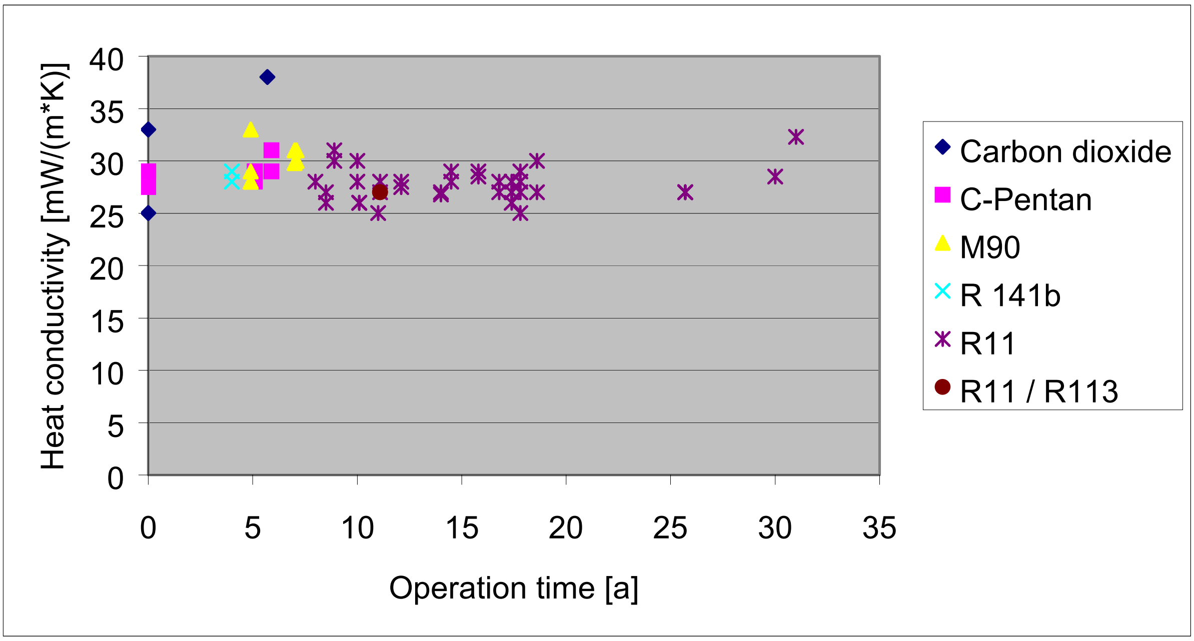
At another water penetration test in boiling water, where hydrolysis probably appeared - the reaction products had not been chemically analysed – the foam showed heavy changes: The originally porous foam looked like lamellas after the test. The strength changed from hard and strong to brittle and crumbly [15].

[1] Hydrolysis is the decomposition of long-chain compounds by a reaction with water.

In case the composite dissolve in the course of deterioration, the water and air spread would be eased in the foam. This causes increasing the heat conductivity and chemical ageing through oxidation and hydrolysis. Furthermore, the absence of composite produces friction and abrasion in the area between isolation and jacket pipe or isolation and medium pipe. Through this the mechanical as well as the thermal properties change: The mechanical load decreases and the heat conductivity increases.

3.3.1 Change of heat conductivity

To the presentation of correlation between operation time and heat conductivity for polyurethane isolations while praxis deterioration are not enough data available. Data of many measurements of different types of pipes at several deterioration stages are needed for positioning statistic correlation. This is going to be the challenge for the next years.
The conclusions of existing heat conductivity measurements applied to the operation time without standardisation show the following picture:



Picture 7 *Heat conductivity of PUR-foams at district heating pipes dependant on propellants and operation time [17]*

Standardisation with the known practices – through the Arrhenius equation – produces no reasonable results in accordance to the cognition of the research project "Thermal history of PUR-foams at practice aged preinsulated bonded pipe systems in terms of heat conductivity and strength" [11].

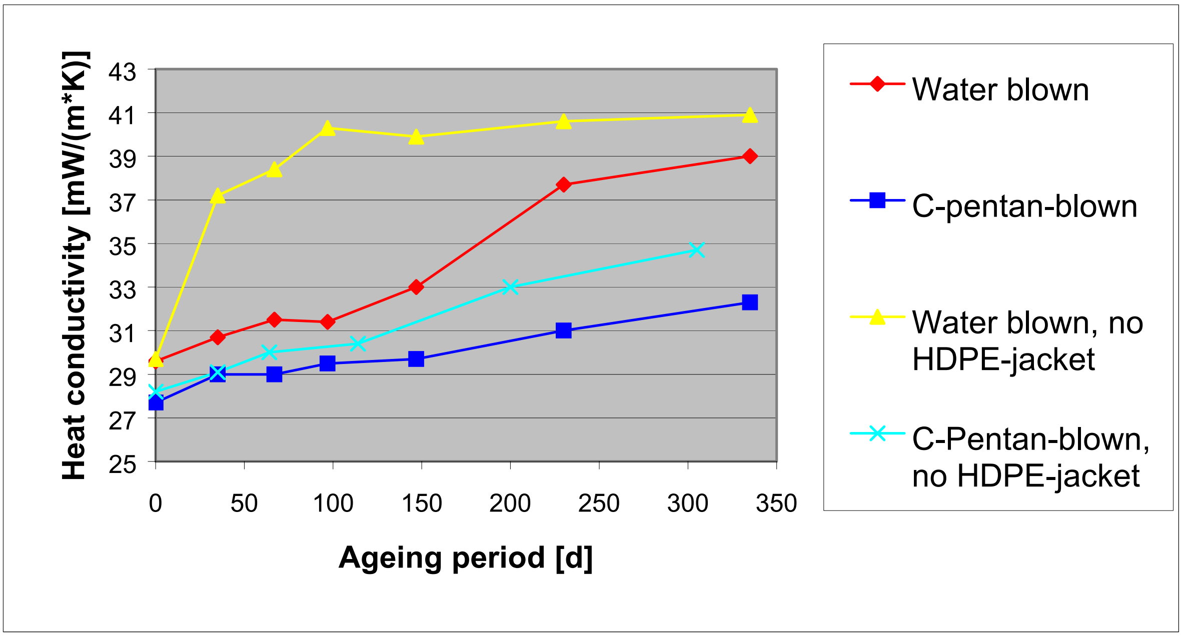
Today pipes with PUR-foam blown with several blowing agents are used. Until the middle of the '90th the polyurethane foams had been blown with CFC and HCFC like R11, R141b and R142b predominantly. The organohalogen compounds have many benefits – low heat conductivity, non-flammability, low diffusion coefficients,... – but they are ecological not passable because of the ozone destruction impact. Nowadays carbondioxide and cyclopentane are mainly used as propellants. In a few cases the vacuum technology is used. This influences the heat conductivity directly:

Gas/ Fluid/ Solid	**Heat conductivity [W/(mK)]**								
	-25°C	**0°C**	**10°C**	**20°C**	**25°C**	**47°C**	**50°C**	**66°C**	**100°C**
$CO_{2(g)}$	0,013	0,015			0,016		0,018		0,022
$C_5H_{10(g)}$					0,013			0,015	
$C_5H_{10(l)}$						0,123			
R 141$b_{(g)}$					0,010				
R 11 ($CCl_3F_{(g)}$)				0,008	0,008				0,011
Dry Air		0,024			0,026				0,031
$H_2O_{(g)}$		0,0165 *			0,0183 *				0,0248 *
$H_2O_{(l)}$		0,561	0,580		0,608		0,644		
Polyurethan				0,260					

* at saturation

Table 3 *Heat conductivity of miscellaneous chemical substances depending on temperature [10]*

Particularly with cold going pipes it must be pointed out, that high molecular propellants – e.g. cyclopentane (C_5H_{10}) – may condense in the polyurethane foam. The condensation of the propellants leads to a high rise of the foam's heat conductivity because the liquid propellants – as one can see in table 3 – features clearly higher heat conductivity than the gaseous.
In the past the heat conductivity of some artificially aged district heating pipes was measured. It showed, that the heat conductivity proceeds asymptotically to a maximum value. Here are some examples of one test run:

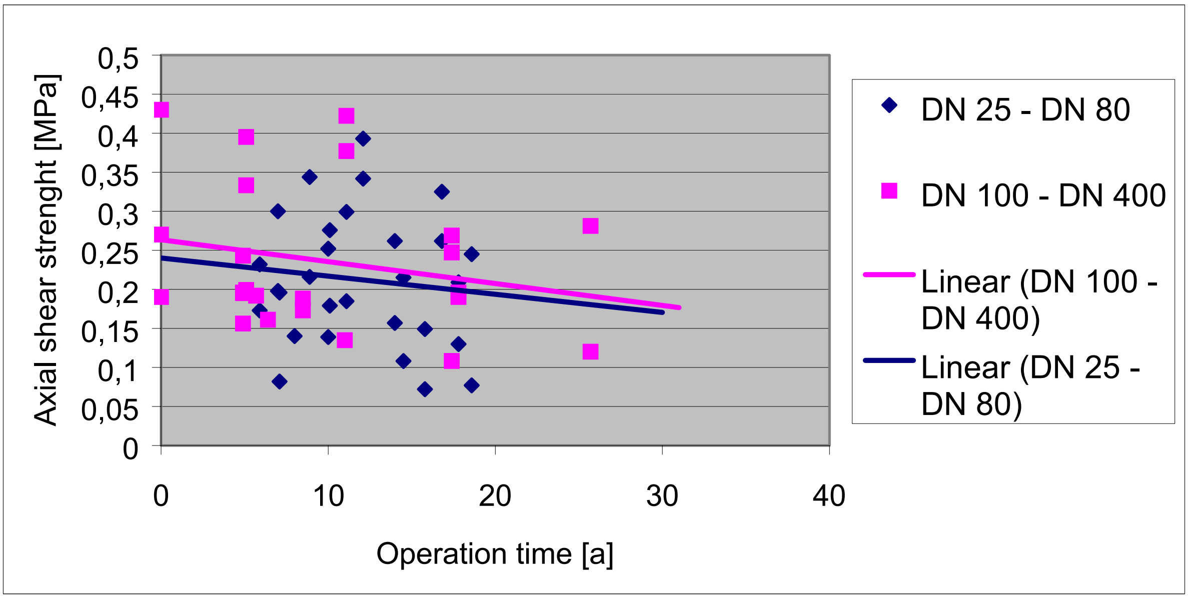


Picture 8 *Heat conductivity depending on the ageing period of artificially aged district heating pipes. Medium temperature 175°C, ambient air temperature 25°C [16]*

It can clearly be seen, that the heat conductivity raises faster and reaches the maximum value earlier at the water blown probes – propellant is CO_2 from the isocyanate-water reaction – than at the cyclopentane blown foams. Also outstanding is, that the missing HDPE-jacket has a smaller stake on the heat conductivity changes of cyclopentane blown foams than on water blown pipes. This can be explained by the permeation coefficients as in table 2.

3.3.2 Changes of shear strength

Through the propellant diffusion out of the foam there may result a temporary depression to the foam. Thereby the compression strength falls momentaryly.
Long-ranging cyclopentane or CFC (e.g. R11) diffusing and dissolving in the cell walls extends the gap between the polyurethane molecules. Thereby the van der Waals forces are lowered. These cause the reduction of mechanical strength. The solubility of R11 in polyurethane is 2 to 5 times bigger than the solubility of cyclopentane.
At the status quo of science the strength of polyurethane foam isolation is decreasing with the age.



***Picture 9** Axial shear strength of plastic sheathed pipes [17]*

At picture 9 a conclusion between the operating time and the shear strength of the aged plastic sheathed pipes in district heating networks under natural conditions can be drawn. From the described measured values it is not clear if this conclusion is linear or different. Unfortunately, no designation to the initial state of the pipes is possible. So the measured values may result from changes during the pipe production in the considered period.
Especially interesting to the measured values is the fact that no conclusion to the pipes used in the supply and return system can be traced. Sometimes ageing tests in the FFI showed that the strength at higher test temperatures raises compared to lower test temperatures. This is an evidence, that the Arrhenius law is not universal for in praxis aged polyurethane foam isolations.

Particularly through the limited expansion in the pipes stress develops. Hot going pipes are, if they are not flexible, thermal or mechanical pre-stressed as well as equipped with compensators of different types to reduce the maximum stress. Therefore, an excess of compression strength is not expected in normal operation. Only the excess of the planned operating temperature may cause the allowed compression strength. In this case cracks and irreversible deformation results. If a pipe is temporarily out of order, cracks and irreversible deformation – like that by the excess of the maximum compression strength - caused by excess the maximum tensile strength may appear.
According to the actually known experimental results no prediction can be made, where the collapse appears. It is to be expected, that the polyurethane foam and the PE-jacket concludes at first. Than the steel pipe follows because the heat expansion coefficient of polyurethane foam and PE-HD is 4 to 20 times higher than the coefficient of steel and the steel features a much higher tensile strength.
Daily or seasonal variation of temperature cause load alternation in the components of the pipe systems. If a numerous variation of temperature happens, the danger of excess of the endurance strength exists. In this case the isolation, the medium pipe and the jacket pipe loses the operability.

4 Result

Heat conductivity and mechanical strength are caused by many factors. Exact conclusions of property changes of polyurethane foams are as yet not available. Every presented calculation model is not applicable to every case of operation of polyurethane foam insulated pipes. The current state of research does not even allow the conclusion, that the prediction of the life time span and the future heat loss through artificial ageing take place in reality.
Beginning at equation (3) and the passed analysis the following conclusion can be declared:

$$\lambda(t) = Z + D + F + U + G + V + B \quad (6)\ [17]$$

λ(t) *Heat conductivity*
Z *Cell gas composition*
D *Density*
F *Chemical composition of solid frame*
U *Environmental influences*
G *Geometry of cells and pipe*
V *Bond and bond materials*
B *Operating method*

The conclusion for mechanical properties can be given analogue:

$$\tau(t) = z + d + f + u + g + v + b \quad (7)$$

$\vartheta(t)$	*Strength*
z	*Cell gas composition*
d	*Density*
f	*Chemical composition of solid frame*
u	*Environmental influences*
g	*Geometry of cells and pipe*
v	*Bond and bond materials*
b	*Operating method*

Loading factors are included to the summands of equations (7) and (8). Today it can not be reviewed, if the aspired calculation model will be exclusively based on experimental or theoretical identifications. The absolute theoretically determined equations would only be numerical unlockable, because the individual terms are all interdependent. On this account creation of approach with statistical procedures (interpolation polynomal) and adopted measured values of existing pipes is worth to consider. But measured values are absolutely necessary for the determination of interpolation polynomal .

The current database is problematical. Numerous research institutes and companies are working on the development for calculation methods of rest durability and determination of the future heat losses. The data exchange between the institutions is not very extensive so far. Reliable measured cell gas profiles over the radius are not really available. Therefore all details on diffusion processes are based on presumptions and mathematical-physical models. Furthermore no detailed models on chemical ageing due to measured values exist up to date. No known calculation model includes the deterioration of the solid fraction.

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