Development of an empirical method for determination of thermal conductivity and heat loss for pre-insulated plastic bonded twin pipe systems

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ABSTRACT

Pre-insulated twin pipe systems (PTPS) for heat distribution offer advantages for heat supply companies. Trench dimensions for heat supply systems of District Heating (DH) networks might be reduced using these pipe systems. This reduces costs in civil engineering. Additionally heat loss of the DH network may be reduced, that decreases operational costs of these systems. On the other hand, operational heat losses of PTPS significantly differ in many cases from theoretical heat loss of PTPS. This may inhibit the application of this technology in DH networks.

Against this background, a standard measurement procedure of thermal properties of PTPS shall be developed, validated and tested at the Fernwärme Forschungsinstitut (FFI). These tests shall be based on standard measurement procedures for single pipe systems described in EN ISO 8497 and modified for PTPS. Within this context, preliminary tests are done at FFI. Numerical simulations of heat loss are done at IGTH and iteratively fitted to data generated from measurements at the same time.

Numerical simulations of stresses occurring due to operational temperatures for PTPS are done in a second step. Internal stresses due to temperature gradients within PTPS as well as external stresses due to interactions of PTPS with the bedding material and ground will be examined. In addition, interactions of bedding materials, operational conditions and heat losses in situ will be assessed.

First results obtained are presented in this paper. Focus of this paper is on development of a standard measurement procedure for thermal properties of PTPS, as well as results of numerical calculations regarding heat loss of these systems. One goal of this project funded by the "BMWi – Federal Ministry for Economic Affairs and Energy", is to discuss and mirror project results in order to modify existing standards, e.g. EN 15698, EN 15632 and EN 13941. Defined quality standards for PTPS, verified by standardized measurement procedures for PTPS, will increase the acceptance of PTPS in the DH sector. This supports small and medium sized enterprises (SME) using and producing PTPS.

1. Introduction (FFI)

The central role of the "Heat Turnaround" becomes obvious regarding the primary energy consumptions of the European Union [1]. Therefore, the reduction of primary energy consumption is required. DH systems attached to Combined-Heat-and-Power (CHP) plants enable energetic efficiencies η_{en} well above 85% and offer

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a widespread, robust and long-term tested possibility to use primary energy most responsibly and efficiently [2].

However, further developments are necessary in order to adjust DH systems according to future challenges, e.g. integration of Renewable Energy Sources (RES) or transformation to Low-Temperature and Ultra-Low-Temperature (LT and ULT) DH networks [3, 4]. Within this context, PTPS are a promising technology for the DH sector. This technology (i) facilitates expansions of DH in cramped urban areas as well as (ii) cost-efficient developments of DH potentials in urban, suburban and rural areas at (iii) potentially higher energetic efficiencies η_{en} than single pipe systems. On the other hand, the utilization of PTPS is still undermined by reservations of energy-supply companies running DH piping systems, as

- Heat losses q occurring in situ are well above heat loss expected according to specifications of PTPS manufacturers, see Figure 1 and
- Calculations on stresses occurring within PTPS and between PTPS and surrounding soil have not been standardized yet.

Against this background, a research project on the "Development of an empirical method for the determination of the thermal conductivity and heat loss for pre-insulated plastic bonded twin pipe systems",

funded by the BMWi – Federal Ministry for Economic Affairs and Energy has been launched in order to meet these challenges and support the "Heat Turnaround".

2. Background information on Pre-insulated twin pipe systems (PTPS)

Pre-insulated plastic bonded single pipes(PTPS) according to EN 253 are the major DH piping system utilized in the EU achieving energetic efficiencies η_{en} in heat distribution around 89% [5, 6]. However, these energetic efficiencies η_{en} may be significantly lower in small DH systems run in rural or suburban areas [7]. Heat losses q occurring are depending on the (i) local boundary conditions of operation (temperature; demands) (ii) quality, as well as (iii) thermal conductivity of thermal insulation and soil, (iv) geometry and design of piping system and (v) the geometry and design of the DH piping trench. Heat losses q occurring for these single pipe systems might be calculated by analytical and approximate approaches and measured according to EN 253 e.g. [5] and [8, 9].

Alternatively, PTPS according to EN 15698 and EN 15632 are available on the market [10, 11]. However, specific reservations against this technology retard the implementation of this technology.
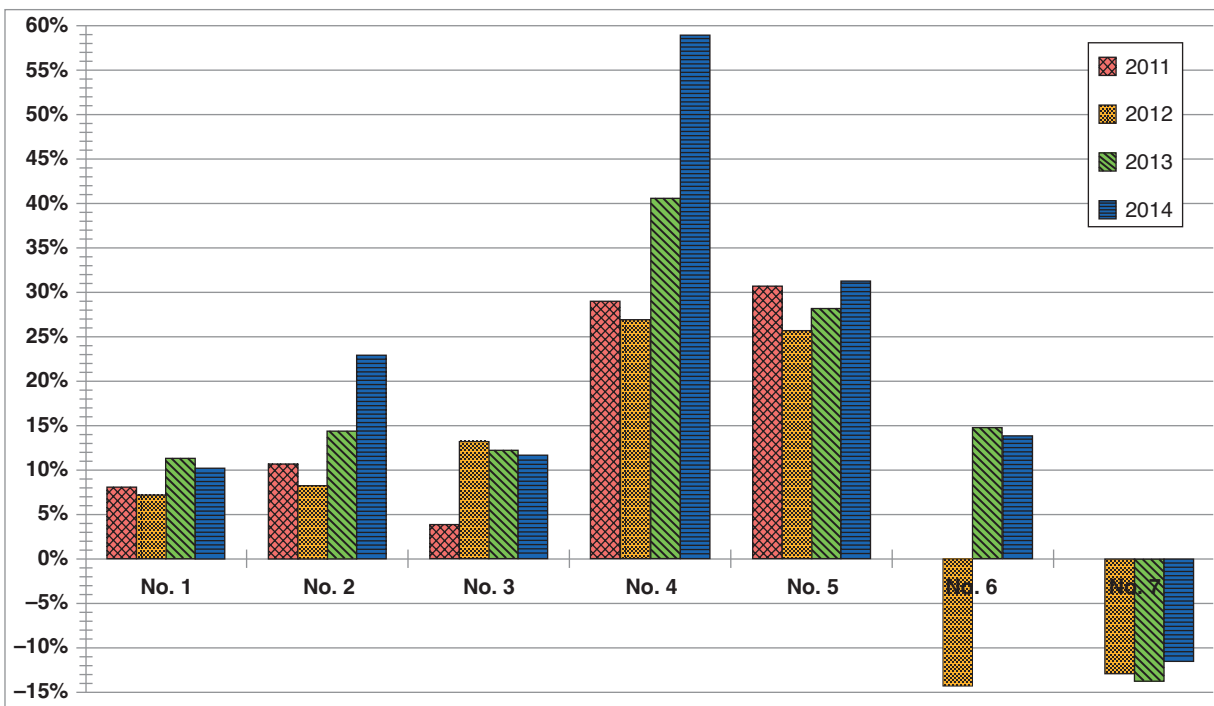

Figure 1: Deviations between heat loss in situ and heat loss expected according to specifications of PTPS manufacturers (basing on operational data of DH system operators and e. g. [18], [19])

2.1. Reservations against pre-insulated twin-pipe systems

PTPS contain two service pipes (e.g. steel or polyethylene) within one casing pipe (mainly polyethylene). The space (gap) between the two service pipes and the casing pipe is filled with a thermal insulation. Polyurethane foam is the most common material for thermal insulation in bonded PTPS. Multiple layers of polyethylene foam are used in non-bonded PTPS.

Generally speaking, the geometry of twin-pipe systems is more complex than the geometry of single pipe systems (cylindrically symmetrical), s. Figure 2 a) and 2b). In addition, different types of PTPS are available on the market, s. Figure 2c) an 2d). Thus, most different technological aspects have to be considered regarding (i) heat losses q occurring and (ii) pipe statics.

- External heat losses q occurring for PTPS cannot be calculated in an analytical way. Therefore, approximate solutions for the calculation of heat losses q or FEM simulations are required [12, 13]. The thermal conductivity λ_{ins} of thermal insulations within PTPS cannot be measured with
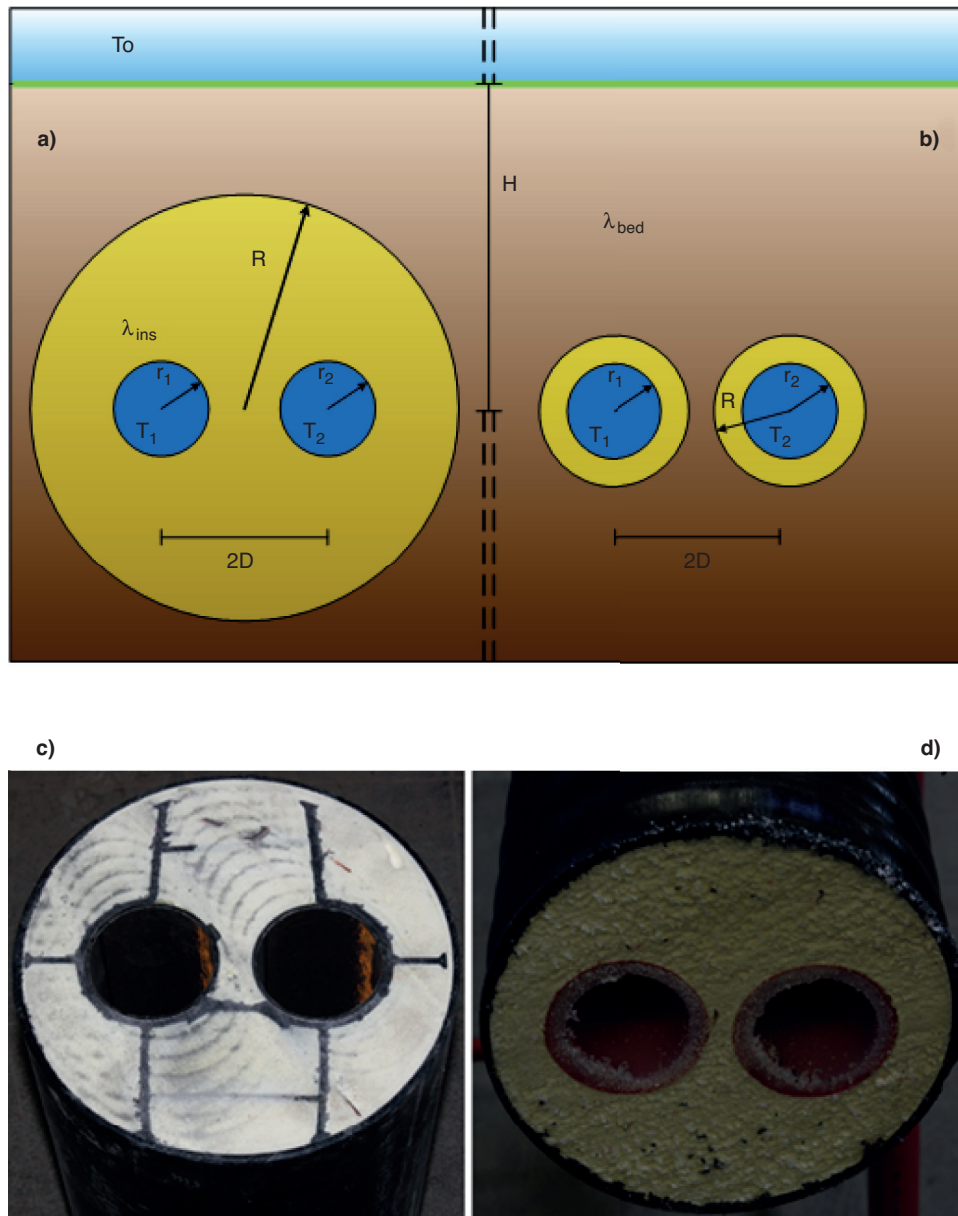

Figure 2: a) Scheme of PTPS ; b) Scheme of single pipe system, c) PTPS according to EN 15698; d) PTPS according to EN 15632

a similar measurement procedure as it is used for single pipe systems. Thus, measurements on thermal conductivities λ_{ins} and heat losses q of PTPS have to be carried out at single pipe systems [14]. Unfortunately, conditions during production of PTPS and single pipe systems differ. This systematically effects thermal conductivities λ_{ins} and heat losses q and makes measurements rather non-reliable. As a consequence, DH network operators have rather strong reservations against the implementation of PTPS.

- Internal heat loss q_{int} between the supply and return flow of the service pipe might be quantified by approximate calculations of heat losses q (for PTPS and single pipe systems) [13]. According to these approximate calculations, internal heat losses q_{int} of PTPS seem to be rather significant. However, these internal heat losses q_{int} are not quantified within specifications of PTPS given by manufacturers. That diminishes the acceptance of this technology once again.

- Internal stresses within PTPS occur due to temperature gradients between the service pipes. These stresses are related to internal temperature fields $T(\varphi, r)$. However, these internal temperature fields $T(\varphi, r)$ are not known yet. As internal stresses may influence the service life (operational lifetime) of PTPS, uncertainties regarding asset and maintenance strategies for PTPS hinder the implementation of PTPS.

- External stresses between PTPS and the surrounding bedding material occur due temperature cycles of the PTPS. These stresses are related to internal stresses within the PTPS, which are not known, yet (see above). However, external stresses are of major importance for (i) pipe statics and (ii) service life (operational lifetime) of PTPS. Thus, uncertainties concerning asset and maintenance strategies occur, which again hinders the implementation of PTPS.

In addition, energy suppliers running DH report of major practical problems connecting PTPS to single pipe systems. Summarizing, DH network operators have strong reservations against the implementation of PTPS.

In order to meet these reservations, a simple and empirical method for the determination of thermal conductivities and heat losses q of PTPS will be developed. This development will be based on metrological investigations on PTPS. FEM simulations on temperature fields within PTPS will be done and adapted iteratively. Adaptions will be based on metrological investigations in order to approximate internal and external stresses occurring. A standard test for a metrological determination of heat loss and thermal conductivity of PTPS will be realized.

2.2. Advantages of PTPS

The proposed development of standard tests and numerical simulations for PTPS within the research project may diminish reservations against PTPS. This supports the application of these systems within today's DH systems of the 3rd and future DH systems of the 4th generation. (i) Energetic advantages might be quantified on a normative basis based on metrological laboratory tests and FEM simulations, whereas (ii) economic potentials in civil engineering might be realized:

- Heat losses q occurring within PTPS might be quantified on a metrological basis considering (i) external heat losses q from the supply and return towards the environment, as well as (ii) internal heat losses q_{int} between these subparts of the PTPS. Preliminary investigations on PTPS based on FEM indicate relevant energetic advantages in comparison to single pipe systems. Until now a reliable quantification of these advantages is not possible, as standard tests for the measurement of heat losses q_{int} and thermal conductivities λ_{ins} of PTPS are currently not available.

- The first step is developing, describing and evaluating standard tests for quantification of a PTPS. This allows an objective and scientifically based comparison to single pipe systems. Finally, the test setup is simplified to reduce metrological efforts to a minimum setup for in order to measure heat losses q and thermal conductivity λ_{ins}.

- Up to 60% of costs for installation of DH piping systems refer to civil engineering (excavating trenches) according to empirical data. Usage of PTPS may reduce these costs by up to 30%, whereas non-accessible trenches are another cost-optimized option for DH. This makes DH more feasible in most different kinds of DH networks and supports the future expansion.

Basing on objective research on external and internal heat losses q and q_{int} (obtained from metrological measurements), as well as internal and external stresses (obtained from FEM simulations), reservations against the utilization of PTPS are diminished. Thus, PTPS might be implemented more into future and existing DH grids. This opens up economic potentials for the expansion the DH technology and supports the energy and heat turnaround.

3. Scientific Approach and Methodology

PTPS are described within a mathematical model. This model will be evaluated and fitted by means of numerical examinations (FEM simulations), as well as metrological tests in laboratory and in situ. The iterative approach will lead to a (i) simplified mathematical model for PTPS describing heat losses q and stresses occurring and (ii) a standard metrological test application for measurements on heat losses q and thermal conductivity λ_{ins} of PTPS.

3.1. Laboratory testing: experimental set-up for PTPS within climate chamber

A new test set-up for PTPS shall be developed within the research project in order to (i) quantify heat losses and (ii) thermal conductivities of PTPS at a temperature of 50 °C λ_{PTPS50}. Against this background existing normative standards and test set-ups described for the measurement of on heat losses q and thermal conductivity λ_{ins} are analyzed:

EN ISO 8497 describes a test set-up for the determination of thermal transmission properties of thermal insulation for cylindrically symmetric pipes (single pipe systems). This is achieved by measuring temperatures at inner surface of service pipe and outer surface of casing. In addition performance parameters of the test devices are defined.

According to EN ISO 8497 test specimen must be (i) uniform and of (ii) same dimensions as in situ, whereas the (iii) cross section shall be circular. In addition, (iv) measurements shall be done within a climate chamber, whereas (v) operational temperatures at the outer surface must be sufficiently high to obtain satisfying measurement accuracies (in comparison to the surrounding temperature). Finally, tests shall be done in (vi) horizontal position.

One possible test set-up described in EN ISO 8497 utilizes "protective heaters" in order to minimize influences of

- Axial heat transfers on heat losses q and thermal conductivity λ_{ins} and
- Tangential heat transfers on heat losses q and thermal conductivity λ_{ins}.

Finally, approximate stationary conditions are realized by pre-heating the test specimen.

Basing on temperatures at the inner surface of service pipes and the outer surface of the casing, the performance of the insulation might be quantified. However, the test set-up described in EN ISO 8497 strongly reflects the cylinder symmetry of single pipe

systems in order to calculate heat transfer coefficients of test specimen and minimize metrological efforts.

On the other hand, the geometry of PTPS differs significantly from single pipe systems: Instead of cylinder symmetry, PTPS are axially symmetrical. Thus, tangential heat transfer cannot be minimized by utilizing "protective heaters" within a PTPS. Therefore, the test set-up must be adapted. Considering measurement efforts, these must be significantly higher than the measurement efforts within the test set-up of single pipe systems. Figure 3 gives a scheme of the new test set-up for PTPS following EN ISO 8497 and considering differing symmetries, applying

- 4×5 temperature sensors (Pt100; $T_{0°i}$ … $T_{180°i}$, with i = 1…4) for mapping the temperature distribution $T(\varphi, r = R)_{Metro}$ on the casing, each set of 4 temperature sensors is located along the test specimen (Positions 1 to 4 in Figure 3),
- 4×4 temperature sensors (Pt100; T_{Ret1i}, T_{Ret2i} T_{Sup1i}, T_{Sup1i}, with i = 1…4) for mapping the temperature within the service pipes, each set of 4 temperature sensors is located along the test specimen (Positions A, B, C, D)and
- 4×4 temperature sensors (Pt100; T_{PHS1n}, T_{PHS2n} T_{PHR1n}, T_{PHR2n}, with n = A…D) for fitting the temperature of the protective heaters (Positions A & D) to the temperatures at the end of the test specimen (Positions B & C).

In addition, the temperature in the climate chamber T_{amb} and input of electrical power P_{el} (voltage and direct current) into the electrical heater is recorded. Axial heat losses q_{ax} are minimized by adjusting the temperatures at each end of the test specimen (Positions B & C) to the temperatures of the protective heater ($T_{PHS1A} = T_{PHS1B}$; $T_{PHR1A} = T_{PHR1B}$; $T_{PHS1C} = T_{PHS1D}$; $T_{PHR1C} = T_{PHR1D}$). Additional temperature sensors at Positions A…D serve as a backup in case of possible failures. Measured data are logged every 2 seconds and analysed for steady state conditions. Basing on these examinations, the heat conductivity of PTPS λ_{PTPS50} shall be derived.

3.2. Numerical examinations on heat loss (IGtH)

Due to the utilization of "protective heaters", the mathematical model for heat losses q occurring in PTPS might be simplified. Neglecting axial heat losses q_{ax}, as well as transient influences ($d/dt \approx 0$), heat losses q are generally directed in radial direction and depend on the tangential position within PTPS: $q = q_{rad}(\varphi)$. Furthermore, the axial symmetry of the PTPS model leads to $q_{rad}(\varphi) = q_{rad}(-\varphi)$.
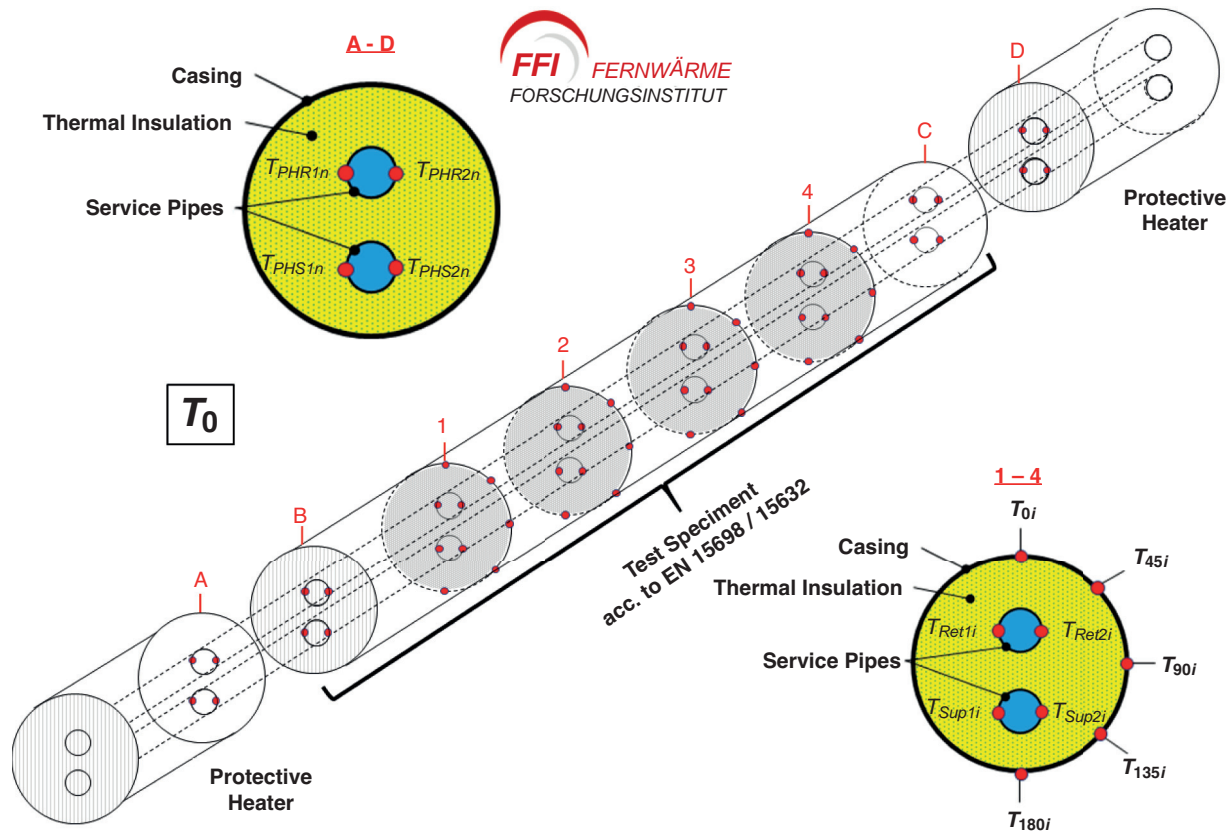
Figure 3: Scheme of test set-up for PTPS following EN ISO 8497.

Within a first step, the finite element model (FEM) for temperature field of the PTPS $T(\varphi, r)$ is set up. However, temperature fields $T(\varphi, r)$ and distributions on the casing $T(\varphi, r = R)_{FEM}$ have to be calibrated taking analytical (e. g. negligible impact of steel service pipes on heat losses q), approximate (e. g. heat losses q according to approximate solutions for PTPS, s. [15, 16]) and metrological considerations into account. Focus of these calibrations is on the metrological results of temperatures on the casing. Adapting metrological and FEM-results on temperature distributions on the casing ($T(\varphi, r = R)_{Metro} = T(\varphi, r = R)_{FEM}$), a calibrated starting point for the temperature field $T(\varphi, r)_{FEM}$ within the PTPS is generated. This again is the foundation of for future examinations on mechanical interactions of the (i) supply and return flow, as well as the (ii) PTPS and the bedding material (second step of FEM simulations). Regarding simulations on temperature fields, three types of basic models are created, integrating plain strain 15-nodes-triangle-elements with 12 Gauß-points:

- PTPS within bedding material for calculation of heat losses q within the ground and during operation,

- PTPS within a climate chamber for calculation of heat losses q following normative standards of single pipe systems (within a climate chamber) and calibration of FEM-models and

- Pre-insulated single pipe systems within bedding material for comparison of efficiencies.

Regarding the FEM models within bedding materials, the mesh generated becomes coarser with increasing distance to the PTPS (e. g. Figure 4a). In addition, the mesh generated by PLAXIS 2D has been refined for all models generated within the service pipe (dark blue), casing (grey) and thermal boundary layer (light blue/ turquoise; e. g. Figure 4b), s. [17].

Thus, FEM-based parameter studies can be done in order to examine heat losses q and temperature distributions $T(\varphi, r = R)_{FEM}$ on the casing. These interact with different (i) types of PTPS (steel service pipe, plastic service pipe), (ii) pipe dimensions, (iii) overburden heights, (iv) temperature fields in the bedding material $T(\varphi, r > R)_{FEM}$ and (v) surface temperatures $T(\varphi, r = R)_{FEM}$ (cf. Fig 4a), (vi) strength of thermal boundary layer (cf. Figure 4b), etc. In
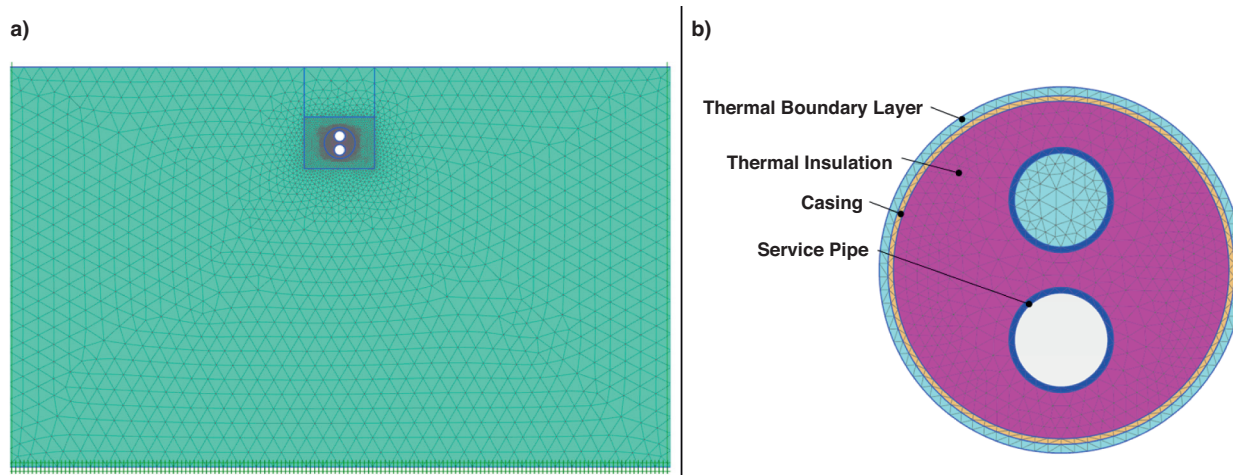
Figure 4: Mesh generated in PLAXIS 2D for FEM-based calculation of the temperature distribution in a) bedding material and b) climate chamber; mesh refinements within the (i) service pipe (dark blue), (ii) casing (grey) and (iii) thermal boundary layer (light blue/ turquoise).
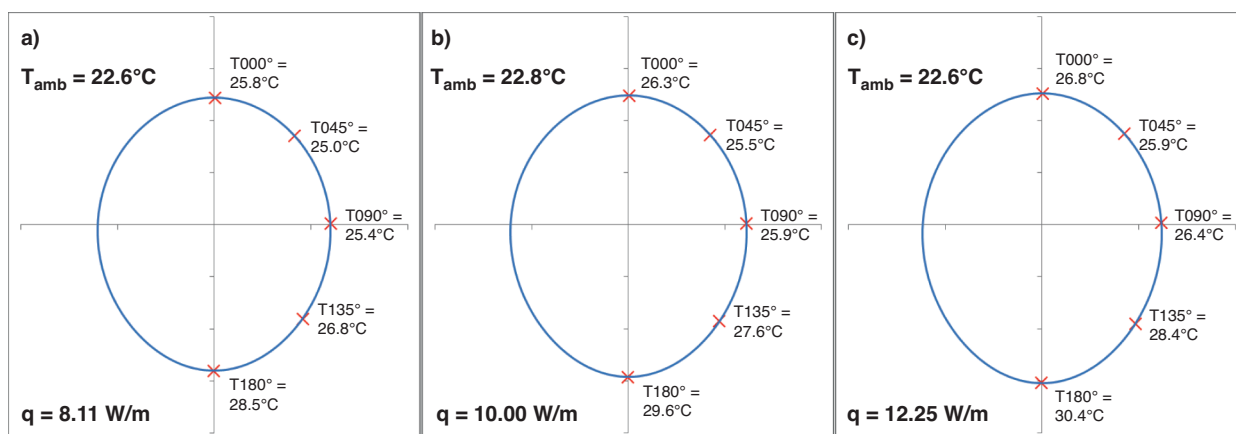

Figure 4: Temperature in the climate chamber T_{amb}; Temperature distribution $T(\varphi; r = R)$ on the casing and heat losses q of the PTPS for different supply flow temperatures T_{Sup} a) T_{Sup} = 70.8 °C; b) T_{Sup} = 79.9 °C c) T_{Sup} = 90.7 °C (metrological results).

addition (vii) spatial variations of material properties (especially the thermal conductivity of the thermal insulation λ) within the PTPS are regarded. However, considering spatial variations of material properties (especially the thermal conductivity of the thermal insulation λ_{ins}) within the PTPS is very challenging due to missing data on λ_{ins} and numerical restrictions in handling the FEM model. Basing on these models, heat losses q, as well as temperature distributions and fields are computed.

4. Preliminary results

Within this chapter, the experimental procedure for measurements on the heat losses q of PTPS is described, whereas first results obtained for different types of PTPS are given (chapter 4.1). In addition, first results of numerical simulations on heat losses q are presented (chapter 4.2).

4.1. Experimental procedure and results
The test set-up schemed above is realized within a climate chamber. For this purpose, an electrical heater is assembled and introduced into the lower service pipe. This electrical heater consists of a (i) flexible corrugated pipe (material: stainless steel) and a (ii) heating wire/ filament. The corrugated pipe and heating wire/ filament are supported by (iii) spacers. These spacers center the electrical heater within the service pipe and integrate temperature sensors (T_{Ret1i}, T_{Ret2i} T_{Sup1i}, T_{Sup1i}, with i = 1…4 and T_{PHS1n}, T_{PHS2n} T_{PHR1n}, T_{PHR2n}, with n = A…D).

During measurements, every 2 seconds, temperatures and electrical power (voltage and current) is logged. In order to eliminated transient influences on heat losses q,

steady state conditions are realized by preheating the PTPS. These are approximately given as soon as the variance of the temperatures on the casing ($T_{0°i}$ … $T_{180°i}$, with i = 1…4) and within the pipes (T_{Ret1i}, T_{Ret2i} T_{Sup1i}, T_{Sup1i}, with i = 1…4 and T_{PHS1n}, T_{PHS2n} T_{PHR1n}, T_{PHR2n}, with n = A…D) is below ±0.3 K for 30 minutes. As soon as steady state conditions are approximately given, mean values for temperatures are calculated:

Positions 1…4:
- Temperature Casing: Calculation on a basis of 4 × 900 measurement points on the same angular position (e. g. mean value of $T_{0°i}(t)$, for i = 1…4 and t = 0…900s),
- Temperature Service Pipe: Calculation on a basis of 4 × 900 measurement points (e. g. mean value of $T_{Ret1i}(t)$, for i = 1…4 and t = 0…900s),

Positions A & D:
- Temperature Service Pipe ("protective heater"): Calculation on a basis of 900 measurement points (e. g. mean value of TPHS1n(t), for n = A; D)

Positions B & C:
- Temperature Service Pipe (test specimen): Calculation on a basis of 900 measurement points (e. g. mean value of $T_{PHS1n}(t)$, for n = B; C)

In the course of the experimental procedure, each test specimen is examined at 3 different temperature levels. These temperature levels depend on the type of PTPS examined: PTPS according to EN 15698-1 (material service pipe: steel) or PTPS according to EN 15632-2 (material service pipe: plastics). Temperature levels deviate due to the aim of the testing procedure, which is a determination of the thermal conductivity at an operating temperature of 50 °C λ_{PTPS50}. Thus, PTPS with steel service pipes are examined at higher temperatures than PTPS applying plastic service pipes. First results of examinations on these two types of PTPS (Nominal Diameter of service pipe: DN 50) are given in Figure 4, correlating the temperature difference between casing and the climate chamber ΔT and angular position ΔT(φ).

4.2. Numerical simulations (IGtH)

Basing on the generated models, first FEM simulations have been realized for average thermal conductivities λ_i (i= ins; steel; …) of the (i) air surrounding the PTPS in a climate chamber, (ii) the casing (polyethylene), (iii) the service pipe (steel) and approximate values for the (iv) thermal insulation (polyurethane foam), s. Table 1.

Thus, first FEM simulations on temperature distribution ΔT(φ; r) and heat losses q have been run for a "PTPS within bedding material". These PTPS apply two service pipes of a nominal diameter of DN 100 (outer diameter: 114.3 mm; supply run at 55 °C and 66 °C) and a casing diameter of 355°mm and 400°mm (DN°100°+°DN°100/355; DN°100°+°DN°100/400). FEM results for heat losses q were calibrated according to metrological results obtained at FFI prior to this research activity and prior to measurements within the climate chamber (s. chapter 4.1). Deviations in FEM and metrological results were negligible (< 2%), s. Figure 5. Thus, a first reliable FEM model for heat losses q occurring has been generated, whereas metrological results on temperature distributions $T(\varphi, r = R)_{Metro}$ on the casing were not available for calibrations, yet.

Basing on the first FEM model, simulations for "PTPS within a climate chamber" have been run, in order to obtain the temperature field T(φ; r) temperature distribution T(φ; r = R) on the casing and heat losses q. The PTPS examined applies two service pipes of a nominal diameter of DN 50 (outer diameter: 60.3 mm, supply temperature T_{Sup} = 70/80/90 °C) and a casing diameter of 200 mm (DN 50 + DN 50/200), s. Figure 6. FEM results for heat losses q and FEM temperature distributions $T(\varphi, r = R)_{Metro}$ on the casing were obtained, s. Figure 7.

5. Summary and Outlook

Metrological examinations on PTPS applying steel service pipes with a nominal diameter of DN 50 (DN 50 + DN 50/200) have been carried out, following the experimental test set-up of EN ISO 8497. In addition, numerical simulations for these systems have been carried out. In order to compare metrological and FEM results, heat losses q, temperature differences between the casing and the climate chamber ΔT(φ; r = R) = T(φ;

Table 1. Thermal conductivities of PTPS-parts.

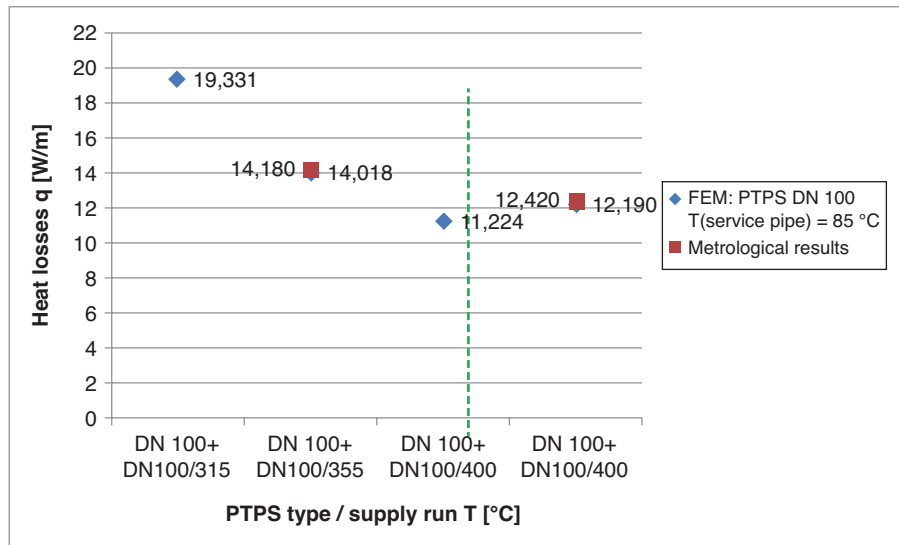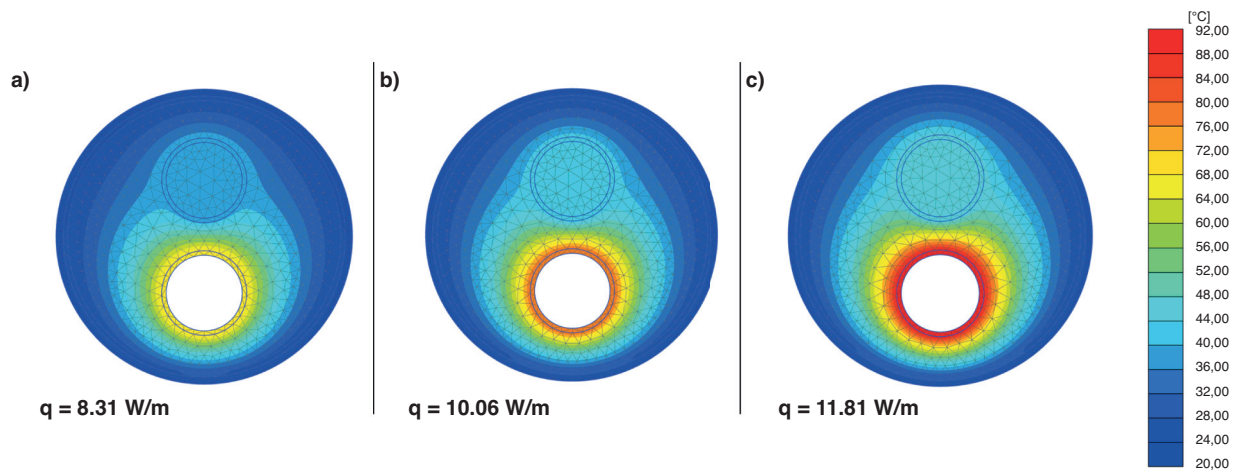| Material	λ [W/(mK)]	Material	λ [W/(mK)]
Air	0.026	Insulation (PUR: polyurethane foam)	0.027
Casing pipes (PE: polyethylene)	0.4	Service pipes (steel)	55.2

Figure 5. Heat losses of simulation and reference tests

Figure 6: Temperature field T(φ; r) in the PTPS and heat losses q according to FEM simulations for different temperatures in the supply T$_{sup}$ (lower pipe) a) T$_{sup}$ = 70 °C; b) T$_{sup}$ = 80 °C; T$_{sup}$ = 90 °C (T$_{amb}$ = 22.5 °C).
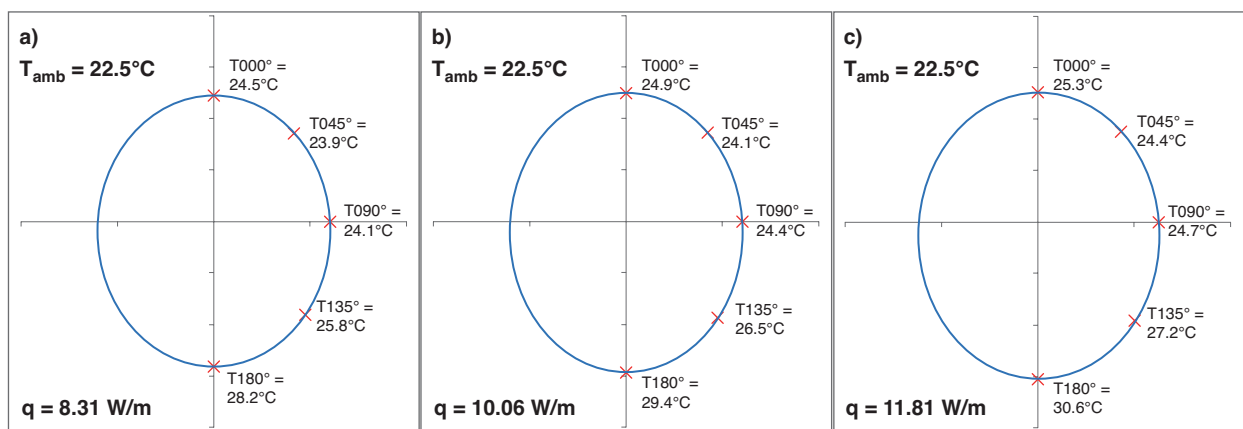

Figure 7: Temperature in the climate chamber T$_{amb}$; Temperature distribution T(φ; r = R) on the casing and heat losses q of the PTPS for different supply flow temperatures T$_{Sup}$ a) T$_{Sup}$ = 70.8 °C; b) T$_{Sup}$ = 79.9 °C c) T$_{Sup}$ = 90.7 °C (numerical results).

Table 2. Comparison of metrological and FEM temperature distributions on the casing.

Position	Metrological Temperatures [°C]			FEM Temperatures [°C]			Deviation
	Sup. /Amb.	Tφ; r = R)$_{Metro}$	Δ T(φ; r = R)$_{Metro}$	Sup. / Amb.	Tφ; r = R)$_{FEM}$	Δ T(φ; r = R)$_{FEM}$	T$_{Metro}$ -T$_{FEM}$[K]
000°		25.8	3.2		24.5	2.0	1.3
045°		25.0	2.4		23.9	1.4	1.1
090°	70.8/22.6	25.4	2.8	70.0/22.5	24.1	1.6	1.3
135°		26.8	4.2		25.8	3.3	1.0
180°		28.5	5.9		28.2	5.7	0.3
000°		26.3	3.5		24.9	2.4	1.4
045°		25.5	2.7		24.1	1.6	1.3
090°	79.9/22.8	25.9	3.1	80.0/22.5	24.4	1.9	1.5
135°		27.6	4.8		26.5	4.0	1.1
180°		29.6	6.8		29.4	6.9	0.2
000°		26.8	4.1		25.3	2.8	1.5
045°		25.9	3.2		24.4	1.9	1.4
090°	90.7/22.7	26.4	3.7	90.0/22.5	24.7	2.2	1.7
135°		28.4	5.7		27.2	4.7	1.2
180°		30.8	8.1		30.6	8.1	0.2

r = R) - T$_{amb}$ and relative deviations in temperatures on the casing [ΔT(φ; r = R)$_{FEM}$/ΔT(φ; r = R)$_{Metro}$]-1 are regarded:

- Heat losses q: Metrological and FEM examinations deviate between +7.1 to +14.0%, whereas deviations drop with raising supply temperatures,
- Temperature differences ΔT(φ; r = R) on the casing: Temperature differences in metrological and FEM simulations deviate between 0.20 and 1.7 K, whereas maximum deviations raise with higher temperatures of the supply T$_{sup}$, s. Table 2.

Prospecting, metrological examinations within the climate chamber will be extended. Thus, PTPS integrating (i) different types of service pipes (PE-X, CrNi-steel, Copper, etc.) and (ii) diameters of service pipes (DN 20, DN 50, DN 100, etc.), as well as (iii) rigid and flexible PTPS systems are regarded. In addition, the metrological test-set up will be integrated into a laboratory DH-trench at FFI in order to gain knowledge on the influence of the bedding material on the heat losses q and the temperature distribution T(φ, r = R)$_{Metro}$ on the casing. Finally, measurements in situ will be done, in order to examine the influence of operational boundary conditions on q and T(φ, r = R).

On the other hand, FEM simulations on (i) heat losses q and temperature distributions T(φ, r = R)$_{Metro}$ on the casing temperature will complement metrological measurements within the climate chamber and (ii) DH-trench. Thus, FEM models may be calibrated, whereas systematic impact parameters on q and T(φ, r = R) may be identified. Within this context,

the (iii) interactions of the supply and return flow of the PTPS will be analyzed. Furthermore, the (iv) sensitivity of results obtained is investigated, focusing on different thermal conductivities (λ_{ins}, λ_{ins}, etc.), overburden heights of the PTPS, surface temperatures and temperature distributions within the bedding material is analyzed. Finally, theses calibrated FEM models for q and T(φ, r = R) are the foundation of FEM examinations on (v) internal within the PTPS and (vi) interactions of the PTPS with the bedding material.

On a short term perspective, the research consortium will identify major impact parameters on heat losses q and the temperature distribution T(φ, r = R) on the casing within the climate chamber. Thus, metrological and FEM results shall converge. Focus will be on differences in production processes of PTPS (continuous, non-continuous) as well as the impact of the thermal boundary layer surrounding the PTPS within the climate chamber.

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