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New approach for asset management in District Heating (DH) networks

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Abstract

Rehabilitation and renovation of district heating networks are mainly based on an event-based maintenance strategy. This means reactive removal of failures and damages and this also describes the uncertainties in the field of accurate lifetime assessment of district heating networks. However, utilities need evaluated estimation of the serviceability of the networks to define the best moment for reinvestment. Interval-based and condition-based lifetime assessment is used by utilities for lifetime assessment e.g. in the branch of sewer and drinking water-networks. First developments can be observed in the transfer of existing decision making tools from other branches to district heating branch. Nevertheless there are several important differences to be taken to account when lifetime assessment is carried out for district heating networks. On the one hand, inspection methodologies from other networks are not transferable because of temperature and pressure loads in DH-networks. Thus condition-based lifetime assessment needs another concept. On the other hand ageing of DH-networks highly depends on the used pipe system and the operation conditions.

The paper presents a new interdisciplinary approach for asset management in DH-networks that was developed by the authors. Different relevant ageing theories for DH-networks were put in order. By a Top-down and Bottom-Up approach these theories are characterized and set in relationship to each other. A first outlook for the next steps to activate these different theories mutually is given, that will make a sustainable rehabilitation planning possible and will lead to new business opportunities in the future.

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Keywords: asset management; rehabilitation planning; lifetime assessment; district heating

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1. Introduction

DH networks are a comparatively young part of the infrastructure. Whereas expansions of supply and disposal networks mainly took place within the last decades and century, DH networks are still expanding and newly built. This is especially true for small scale low-temperature grids uprising in rural and suburban areas. In addition and according to all empirical data available the DH infrastructure seems to be a robust system, fit for resisting high stresses over decades of operation.

Against this background, conclusive insights and findings on the technical service life of these networks are sparse. On the one hand, this is due to an operation of these systems mainly below 50 years, resulting in few empirical and statistical data on the development of the technical service life available. On the other hand, damages and cases of average are rarely occurring due to the robust design of these systems.

This context complicates the definition of a fundamental maintenance strategy for renovation in the DH sector. Statistical methods, utilized in other infrastructural sectors, are not applicable without modifications, as a high amount and quality of data is required. Furthermore, the technical service life is strongly depending on the quality of construction works, operational conditions as well as piping systems and materials utilized. Basing on expert interviews conducted by the AGFW, a general overview on the expected technical service lives of different piping systems is graphically given in Fig. 1 [1].

According to Fig. 1, the variations on the expected technical service lives are quite broad. Regarding the widespread preinsulated bonded pipe system according to EN 253 [2], the variation is between 35 and 70 years of operation, whereas the planned technical service life of these systems according to EN 13941 is just 30 years [3]. Thus, the planned technical service life of these systems is 5 years below the minimum technical service life according to AGFW FW 114 [1]. This difference may suggest that the planning and static design of these systems is quite conservative, e.g. by assuming higher static loads than in reality and therefore integrating major reserves.

Despite of the robust design of DH systems, questions concerning the actual time for renewals and renovations (maintenance) are to be answered [4, 5].

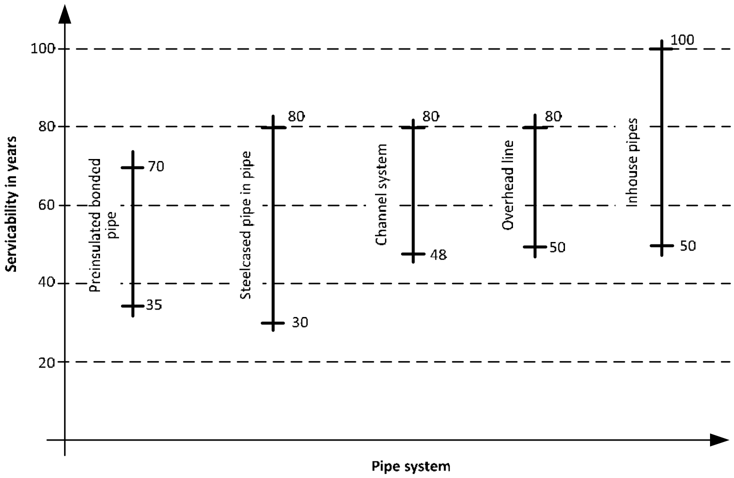

Fig 1. Expected technical service life of piping systems according to AGFW, FW114 [1].

Concluding, an integrated approach for calculating the technical service life or the ageing of DH systems and components within the context of a profound asset- and maintenance strategy is missing. Therefore, the authors reviewed the relevant literature on this topic in order to classify the different types of ageing models and defect mechanisms. The examinations revealed two fundamental approaches for ageing models:

- Bottom-Up Models: The ageing and defects occurring are calculated basing on changes in material properties, e.g. linear and non-linear damage accumulation theories;
- Top-Down Models: Statistical approaches for forecasting the amount of damages occurring for different group of DH component groups and DH component types.

A scheme illustrating the different steps of calculation and computation is given in Fig. 2. Generally, the significance of both models strongly depends on the quality of the underlying data. Following, the advantages, disadvantages and limits of both approaches shall be outlined.

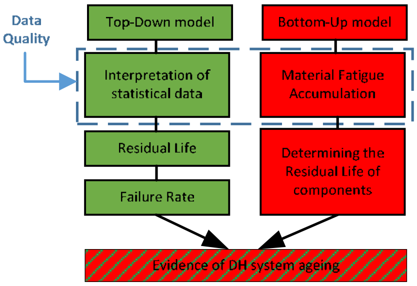

Fig. 2. Flowchart on the mathematical modelling of the residual life time and amount of damages occurring for technical components; Top-Down Models (left) and Bottom-Up Models (right).

2. Bottom-Up Models basing on changes of material properties

Bottom-Up Models examine changes in the materials applied on the DH piping level. Therefore, these models might be very specifically adapted to the system considered. E.g. regarding preinsulated bonded pipes, the ageing of the thermal insulation has a very strong impact on the technical service life of the overall pipe system. Generally speaking, significant changes in material properties occur due to cyclic loads for all piping systems utilized in DH systems.

Therefore, Bottom-Up Models summarize different cyclic loads (e.g. resulting from thermal or hydraulic load cycles and associated extensions/ shortenings) of DH components according to the stresses occurring. Modes at high stresses cause higher damages than modes causing lower stresses. Resulting, a higher share of the technical service life of these components is “consumed” due to high stresses, diminishing the residual life time. Considering material specific Woehler-curves and the type of stress (tensile or compressive), as well as the type of load cycle (swelling, alternating, symmetric, asymmetric, etc.), the increase in damage is quantified. Linear theories on damage accumulation, e.g. [6], neglect plastic deformations resulting from highly dynamic (over-) loads, fatigue limits, preimpairments or load history. However, linear damage accumulation theories are widely utilized due to high (easy) manageability and applicability. On the other hand, major deviations between residual life times calculated and practically reached occur.

Against this background, non-linear approaches for damage accumulation have been developed, e.g. [7–11]. Considering different material properties (yield strength, etc.) fatigue limits, etc., non-linear damage accumulation theories are a major improvement. On the other hand, the more complex modelling of the technical service life and residual life time diminish the manageability and practicability of these models. Generally, linear and non-linear theories on damage accumulation have the following characteristics and (dis-) advantages:

- The quality of calculations strongly depends on the underlying data. Especially the documentation of the load collective is of major interest. These collectives are very different for main pipes, distribution pipes and house connections [3];
- The application of Woehler-curves existing for defined (right-angled) probes under a defined (repeated) load collective for technical components (of DH systems), e.g. corrugated, radial-symmetric compensators under variable loads, is generally possibly but complex and prone to errors [12]. In addition, simplifications and

approximations have to be done in order to calculate the residual life of components having a major impact on these calculations;

- The application of these theories is mainly possible for ductile (metallic) materials and components within DH systems. However, this is rather uncomfortable as a major share of DH piping systems consist of systems combining ductile and no-ductile components;
- Furthermore, the application of damage accumulation theories is restricted to components consisting of one material. Interactions of ductile and non-ductile materials applied in DH components, e.g. of the metallic media pipe and the thermal insulation, cannot be mapped yet;
- Statements on the statistical deviation (e.g. Gaussian deviation) of the technical service life are not given, neither generating Woehler-curves in laboratories, nor considering empirical data of DH systems and components in situ. Thus, bandwidths for a realistic damage rate as well as probable ranges for technical service lives cannot be given.

3. Top-Down Models basing on statistical approaches

Top-Down Models summarize different groups and types of DH systems, e.g. compensators, pipes (of varying nominal diameters) or armatures (valves, etc.). Individual components are hardly considered allowing the integration of statistical data from the overall DH sector. Considering statistical data and assuming distribution functions, these functions as well as the damage rate is calibrated in order to plan monetary funds and personal efforts needed for maintenance. Within this context, different distribution functions are applied [13–17].

3.1. Gaussian Distribution

The Gaussian distribution assumes a symmetric distribution of the technical service life around an average (mean) value described by a bell curve. Different, independent parameters influencing the technical service life are cumulating in an additive way (cf. damage accumulation hypothesis). The width of the bell curve around the average value of the technical service life is described by the standard deviation. Small standard deviations result in a high rate of damages occurring within a short time (of DH system operation). However, the damage rate steadily rises, which is not plausible for the description of piping systems, whereas the residual life time diminishes steadily and monotonic.

3.2. Weibull Distribution

The Weibull distribution is a steady probability function and a generalization of the exponential function. Considering the history (mode of operation) of the system/ component considered, the Weibull distribution describes the technical service life of (brittle) materials. A diminishing residual life is generally suitable for describing piping systems. On the other hand, the damage rate is steadily growing, which is not plausible for piping systems. Furthermore, preinsulated bonded DH-pipes are not necessarily meeting the brittle characteristic required for utilizing the Weibull distribution.

3.3. Herz Distribution

The Herz distribution describes the ageing of piping systems considering three ageing parameters: the ageing factor, the failure factor and the resistance time. Constant damage rates are reached asymptotically. Thus, the deterioration of the piping is constant, as damage rates are not increasing anymore. This assumption seems to be most plausible for the description of piping systems. Furthermore, this assumption leads to a constant residual life of the piping system given that these have been in technical service for a certain time. However, due to a constant share of pipe failures, the remaining stock of these systems finally becomes zero [18].

3.4. Conclusions on Top-Down Models

Concluding, the Herz distribution seems to be most suitable for describing the ageing of piping systems. On the other hand, utilizing the Weibull distribution, good results are achieved as well [1]. Generally, statistical approaches for the description of the technical service life, residual life, damage rate and ageing of DH systems have the following characteristics and (dis-) advantages:

- The quality of statistical models strongly depends on the quality of underlying data. Regarding the broad agglomeration of data from different DH systems needs a profound consideration on the comparability of operational conditions. Besides thermal and hydraulic load cycles, the explicitly integrates most different aspects of installation, quality assurance (during construction, etc.) and commissioning;
- The application of a statistical model depends on the complexity as well as the data quality. Thus, determining different ageing parameters is prone to errors and maybe not possible;
- Utilizing statistical approaches for calculations on the residual life of single, system-relevant components, e.g. compensators integrated within main supply pipes, is not possible. However, especially for these components, failures are intolerable and must be avoided.

4. Summary and prospects

Examinations conducted showed, that an integrated and integral computational approach for the description of the ageing of DH systems and heat distribution systems does not exist. The relatively low age, especially regarding low-temperature DH networks in rural areas, robustness of DH systems, as well as the strictly unilateral consideration of different ageing mechanisms in the past seems to be the reasons for this conclusion. Independent of the model applied (Top-Down or Bottom-Up; damage accumulation or statistical), the calculation and computation of the residual life and forecast of damages to come has major deficits.

On the one hand, an excessive effort has to be done applying Bottom-Up models basing on damage accumulation in order to obtain a general overview on the condition of the DH system in focus. Furthermore, these approaches are prone to errors and show a limited reliability for a quantification of the technical service life and residual life.

On the other hand, Top-Down models are generally incapable of including operationally conditioned changes of material properties, as standardized, statistic distribution functions are applied. Thus, the failure of system-relevant components is still possible, due to the utilization of few data available. Resulting, DH components may still break down unexpectedly, whereas the early exchange previous to the end of the technical service life is the alternative.

Prospecting, the combination of both approaches in order to combine their advantages and reduce their disadvantages, may overcome these conclusion. Therefore, an intensification of researches in this field is recommended by the authors, in order to find a profound basis for future asset and maintenance activities and strategies for the DH sector.

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