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Long-term Analysis of the Operation of the Urban Heating Network Including Aspects of Environmental Protection

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1. Introduction

The primary factor determining the overall quality of pipelines is their leak-tightness. Engineers involved in the operation of heating networks believe that there is no perfectly leakproof system. Leakages are a natural phenomenon during the operation of heating networks. The technical condition of the system and its extension should be an element of care for the technical infrastructure at the local level (Lizakowski et al., 2016).

It is not possible to precisely determine the time or place of leakages' occurrence (one can only forecast them). The concept of leakages can be defined as various types of network damage that cause water leakage. It can be both the leakage in the pipeline and the leakage of the network fittings. The leakage will be both a small leak invisible on the surface of the ground, as well as a violent failure causing a massive water leak, flooding of streets, basements and underground structures. Depending on the scale of the leakage, appropriate measures and equipment necessary for its removal and trained employees should be involved (Troja et al., 2019).

All leakages, both small ones and those of a larger scale, cause significant losses for heating companies (direct and indirect). Direct losses result from the following reasons:

- the district heating water is treated water, the appropriate preparation of which costs about PLN 3-6/m^3 (Chorzelski et al., 2013),
- the cost of its pumping into the network was incurred (costs of electricity consumed by refill pumps),

- district heating water always has a temperature higher than ambient temperature, depending on the so-called heating curve,
- threats to human health and life (e.g., scalding with hot water) due to unsealing of the heating network,
- leakage causes water losses depending on the time of leakage.

Indirect losses are much more difficult to quantify and include aspects such as:

- negative perception of the company,
- lowering customer satisfaction,
- maintaining the brand's position.

To limit the losses generated by leaks and their negative impact on environmental protection, they should be detected and removed as soon as possible.

Although modern district heating networks are being constructed as networks made in pre-insulated technology together with a built-in system to detect breaks in insulation continuity and moisture (the so-called alarm system), most heating networks utilized in Poland are made according to the traditional channel technology. They are the oldest and at the same time the most prone to failure component of the heating system, which is why leak detection in these networks is so important.

Leak detection methods in district heating networks can be divided into several groups according to the scheme shown in Figure 1.

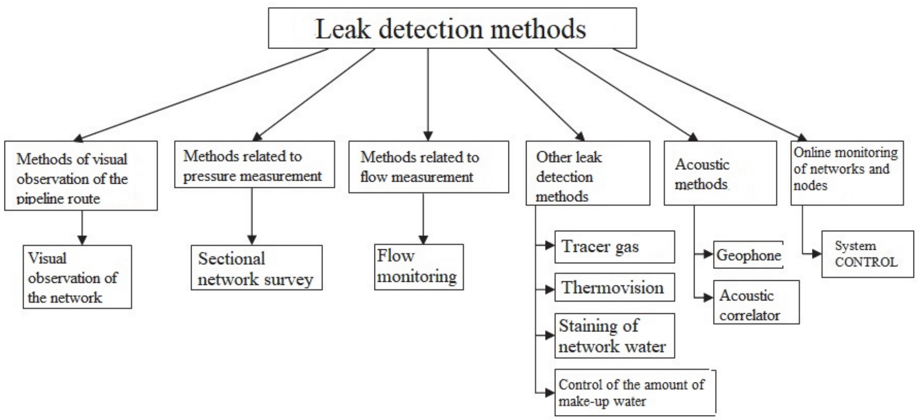

Fig. 1. Division of methods for locating leakages in heating networks

Table 1 presents the advantages and disadvantages of the methods for locating leakages in heating networks presented in Figure 1.

Table 1. The advantages and disadvantages of leak detection methods discussed in the article

Type of method	Advantages of method	Disadvantages of method
Visual observation of the network	Lack of specialized equipment, simplicity of the test, short time of the test, low cost of testing, the possibility of carrying out the test by workers during daily operations	The difficulty of unambiguously assessing the location of the leak
Sectional network survey	An uncomplicated measurement method, no specialized equipment required	Strongly depends on the leak-tightness of the network valves, the need for efficient pressure gauges, the need for access to chambers, does not specify the point of occurrence of leaks
Flow monitoring	Simplicity, fast analysis of measurements	Necessity of access to pipelines, strong impact of measurement accuracy (human factor), strong influence of sediments in pipelines, flow free of gas and steam bubbles, does not determine the place of leakage
Control of the amount of make-up water	Information for the company about the failure and the need to try to locate the leak by other methods	Small leaks are not detected, it does not determine the location of the leak
Tracer gas	Very high sensitivity, high test speed, allows one to detect the smallest leaks, allows one to test deeply located systems	The need for direct access to the pipeline or device, ambiguity, cannot be carried out during rain and wind

Table 1. cont.

Type of method	Advantages of method	Disadvantages of method
Thermovision	Comfortable measurement from the ground surface with current temperature preview, non-invasive	Strong influence of weather conditions (sunshine, wind) and time of day, quite high price of the device, sometimes ambiguity of measurement
Staining of network water	A straightforward method to use, low cost of testing	It does not specify a leak point; it is only suitable as an action to help locate leaks
Geophone	The exact method of locating the failure, the possibility of testing without access to the pipeline, one person can conduct the test	It requires much experience from the operator, a strong impact of external noise, the need to dry the heating channel when the leakage is in the water
Acoustic correlator	A very accurate method of leak detection; it does not require as much experience as geophone measurement; accuracy and speed of failure location	Necessity of access to two heating chambers, high price of the device, strong impact of the corrosion of pipelines, constant diameter of the measured section required, need to dry the heating channel when the leakage is in the water, sound disturbance caused by fixed points and pipeline supports
CONTROL comprehensive diagnostic and safety system	The exact method of leak detection. One system performs many tasks: leak location, access authorization, telemetry, high speed of operation	Necessity to train employees of companies and system dispatchers, high costs of system implementation

Source: the authors' study

When choosing the particular method, one should bear in mind that leak detection depends on many factors, such as pipeline depth, access to heat chambers and pipelines, device operators' experience, atmospheric conditions, external disturbances and economic aspects (test and diagnostic equipment prices). The considerations regarding leakage in water supply networks seem to be cognitively valuable with regard to analyzing the considered issue. Numerical leakage analysis of the water pipe was discussed by Suchorab et al. (2016).

Locating the leakage can be implemented in two ways: with the participation of trained employees and own equipment or entrusting this task to a specialist external company. Regardless of the choice of the method of implementation of the heating network diagnostics, preventive measures should be taken into account, thanks to which high direct and indirect costs generated by unsealing of the heating network, adverse effect on the environment and the health of employees can be avoided. Detection of already created and prediction of potential sites where damage to the heating network may occur is still an urgent problem that provides significant research opportunities. The direction of research on this subject should focus on system solutions based on embedded systems operating in the internal network. Such a system should also have the features of a distributed and remotely managed system.

In the article, based on long-term observations, a multi-criteria analysis of the impact of the heating network of a typical city in Poland on the natural environment and selected aspects of environmental protection was carried out.

2. Description of the analyzed heating network

The article presents an analysis of the operation and modernization of the heating network for over 10 years, i.e., from 2007 to 2016. The tested network provides heating to residential buildings and companies in the city of Kościerzyna. It is currently in 87% pre-insulated and 13% standard channel network. Over the past 10 years, the network has been successively developed to ensure its monitoring.

The control system of pre-insulated network leak-tightness is monitored in a continuous mode by analyzers located in the thermal centers around the city. The leak-tightness of the analyzed pre-insulated heating network is monitored using a pulse security system. The channel heating networks are not equipped with an alarm system informing about leaks.

Table 2 presents the development of individual sections of the heating network for over 10 years. Static measures were used to visualize the changes, i.e., mean value (M), standard error (Se), median (Me), standard deviation (Sd), skewness (Ske), minimum (Min) and maximum (Max) values.

Table 2. Development of the heating network in the years 2007-2016

Termination	M	Se	Me	Sd	Ske	Min	Max
Total length of the network [mb]	382505.78	243650.80	23689.40	808098.30	1.92	4898.41	2017013.53
Length of pre-insulated network [mb]	378491.37	243603.45	19820.90	807,941.24	1.92	1424.91	2012680.03
Cable network length [mb]	4014.41	117.98	4333.40	391.31	-0.58	3473.50	4333.60

Figure 2 presents the percentage changes of sections of the pre-insulated and channel network in particular years and their expansion in those years.

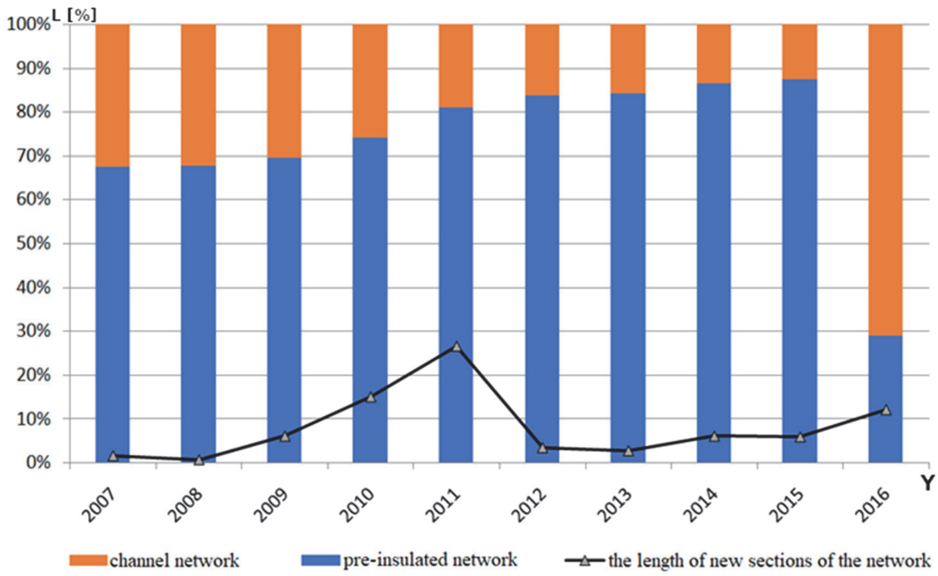

Fig. 2. Percent changes in the length of the ducted and pre-insulated network in 2007-2016

The percentage distribution of changes in the network sections presented in Figure 2 shows that in individual years the heating network was gradually developed. In particular, this development concerned the pre-insulated network, while the new sections of the heating network were most intensively built up to 2011 and in 2011, and then the extension of the network was much smaller. Since 2012, there has been a change in the concept of network development – instead of adding new sections of the network, the existing ones were modernized.

The general trend of modernization taking place over the analyzed 10-year period was that it was heading towards developing the channel network and creating a pre-insulated network.

3. Analysis of the failure and operation of the heating network

The first stage of the analysis of the operation of the heating network was to classify the failures occurring in it and the intensity of their occurrence in particular years. The identified failures were classified due to their place of occurrence, i.e., failures were identified that occurred in distribution network sections and receiving sections. However, the leakage losses were estimated based on water, which had to be replenished. Make-up water is the loss of heat carrier in heating networks (high-parameter network and external receiving installation) divided into:

- loss of the carrier during the operation of the heating network (fittings leaks, pipeline failures, planned repairs and modernization of the network),
- receiving systems (filling and refilling of water losses in the receiving installation after repairs and modernization, sale of heat carrier to recipients).

In the receiving sections, only one single cause was distinguished, which resulted in the need to refill the carrier. These were replenishments after repairs and modernizations of the receiving section, while in the examined period no heat carrier was sold to customers. However, in the distribution sections, three groups of failures were distinguished. The data presented in Table 3 shows that the failures related to the pipeline required most of the replenishment of the carrier, but they were not as intense in the analyzed years. There were years (Fig. 3), e.g., 2012, 2014 and 2015, when such failures didn't occur at all. Replenishments caused by repairs or modernizations constitute the second group of events that required large replenishments of the carrier. Over the analyzed period, they showed a constant trend of around 550 m^3.

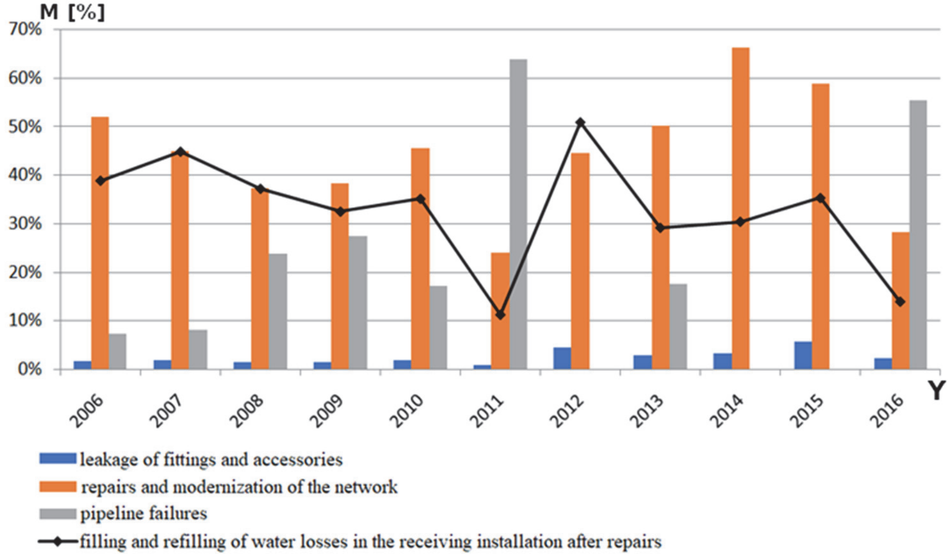

Fig. 3. Malfunctions of the heating network in 2007-2017

Network failures at a negative outside temperature are dangerous, not least because of the discomfort of heat consumers. In extreme cases, they can lead to the destruction of the internal system as a result of their most vulnerable fragments getting frozen up, e.g., in stairways, or other factors.

Table 3 presents, with the use of statistical measures, quantitative changes in network failures. The primary measure of the failure impact assessment on the network was the amount of water that had to be replenished as a result of a given type of failure.

In the history of the analyzed heating network, one major failure of the heating network and several local network failures were noted. The failure in the transmission network from February 1999 consisted of a delivery break for the entire city for 12 hours. Other failures are local, for example, in the Osiedle 1000-Lecia housing estate in February 2012, an outage took place for several buildings for 3 hours (170 inhabitants covered by a time limit), in March 2012 – outage for a few buildings for 3 hours (200 inhabitants covered by a time limit), in December 2016 – failure of the port, without interruption in the supply of heat (utility building), in January 2017 – the failure of the port, without interruption in the supply of heat (utility) January 2017 – the failure of the connection, the reduction in the supply of heat (70 residents covered by a time limit), and in December 2017 – outage for several buildings for 5 hours (500 inhabitants covered by a time limit).

Table 3. Malfunctions of the heating network in 2007-2017

Termination		M	Se	Me	Sd	Ske	Min	Max
Amount of make-up water [m^3]		1368.27	233.67	1198	774.99	2.58	707	3546
Carrier losses during the operation of the heating network	leakage of fittings and accessories	30.45	2.78	34	9.22	-0.09	20	42
	pipeline failures	407.82	204.04	208	676.74	2.48	0	2262
	repairs and modernizations	548.18	44.92	505	148.98	0.92	349	850
Carrier losses in the receiving installation	repairs and modernizations	381.82	22.38	400	74.24	-1.05	250	450

A good indicator of the quality of the network system is the information about the annual amount of water that was exchanged in the system. The examined heating system in this respect belongs to the relatively secure systems, with the norm of water changes in an annual ratio of 4 to 5.

Table 4 presents the changes in indices important for the heating network. In particular, attention was paid to the amount of make-up water, the heat amount needed to heat the carrier for the replenishing, the total cost of heat to replenish the carrier, network total disruption and the amount of water exchange in the system.

Based on the data collected in Table 4 and the distribution of selected factors presented in Figure 4, conclusions can be drawn that refer to the observations noted during the system analysis. In the case of the surveyed network, the most significant year was 2011, in which the most intense investments were implemented. Later, only the modernization of the old network and its development took place.

Table 4. Characteristics of the networking system in 2007-2017

Termination	M	Se	Me	Sd	Ske	Min	Max
Amount of make-up water [m^3]	1313.73	230.26	1186.00	763.68	2.94	707.00	3546.00
Amount of heat needed to heat the carrier for replenishment [GJ]	334.89	57.81	301.18	191.75	2.86	177.74	891.46
The cost of combined heat intended to replenish the carrier [PLN]	12279.73	2215.01	10675.82	7346.36	2.64	6481.55	33142.51
Network total disruption [m^3]	358.73	21.17	388.00	70.23	0.26	271.00	435.00
Amount of water exchange in the system	3.81	0.60	3.70	2.00	1.95	1.60	9.10

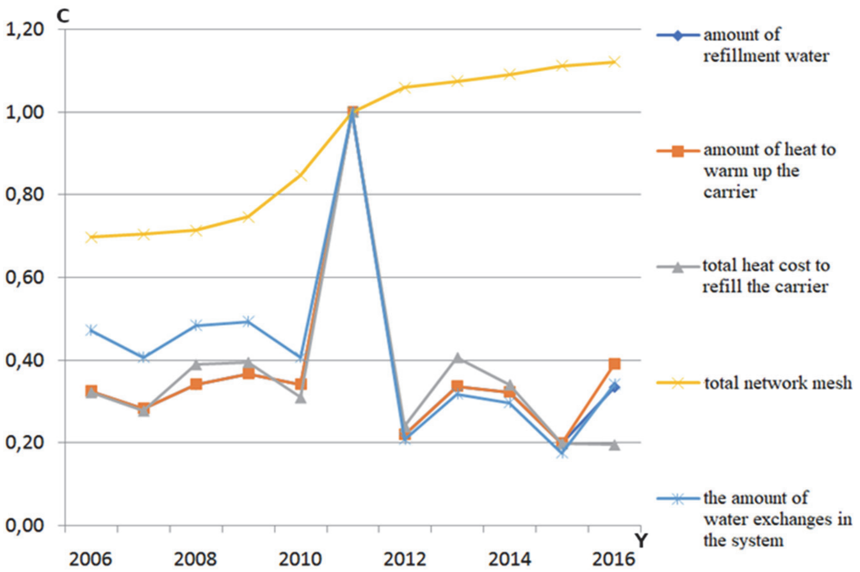

Fig. 4. Distribution of selected networking system coefficients in 2006-2016

Since 2012, the following costs have been reduced by about 10%: the total costs for replenishing the carrier, the amount of make-up water and the amount of heat to be heated. However, the other two indicators have changed a lot because the amount of water exchange has decreased by about 18%, and the total network disruption has increased by about 40%.

4. Conclusions

Detection of already created and prediction of potential sites where damage to the heating network may occur is still an urgent problem that provides significant research opportunities. The research on this subject should focus on system solutions based on embedded systems operating in the internal network.

The analysis of the actual heating network over 10 years allowed one to assess the dynamics of its development and modernization. In this respect, it was noted that the network was intensively developed until 2011 when the most significant investments took place. It can be assumed that in 2011 the development of the network became saturated, which meant that in the following years, network managers focused on the modernization of old sections through their development.

The actions taken related to the expansion and modernization of the network translated into a change in the coefficients that testify to the quality of the heating network and its impact on the natural environment. In particular, the most significant failures occurred before 2011, while later ones were quickly detected and removed.

The investment in the heating network also influenced the improvement of the quality of its operation, which is reflected in a reduction of about 10% of the costs of replenishing the carrier, the amount of make-up water and the amount of heat to be heated. Also, the other two indicators assumed for the assessment purposes have changed even more because the amount of water exchange has decreased by about 18%, and the total network disruption has increased by about 40%.

Based on a long-term analysis carried out for an urban heating network of up to 30,000 residents, it was found that investing in the modernization and pre-insulation of the network translates into a significant improvement in its functioning in a wide range. It contributes to lower costs of its operation, increased customer satisfaction, and positively affects the impact on the natural environment.

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Abstract

The article presents methods for the location of leakages in heating pipelines. The advantages and disadvantages of each of the described methods are presented. The exploitation and modernization of the actual heating network in the city of up to 30,000 inhabitants over the space of 10 years have been characterized. The examined heating network was analyzed for the degree and categories of malfunctions occurring in the examined time space in the network and impact on the natural environment was determined. The article also examines the impact of various factors, such as the amount of make-up water, the amount of heat required to heat the supplementary carrier, the total cost of heat to replenish the carrier, networks total disruption and the amount of water exchange in the system and its impact on the natural environment. At the same time, an assessment of the impact of the modernization of the heating network combined with its munition to reduce the impact of these factors on environmental protection was made.

Keywords:
heating network, network monitoring, heat network malfunctions,
environmental protection, pre-insulated networks

Długoterminowa analiza eksploatacji miejskiej sieci ciepłowniczej z uwzględnieniem aspektów ochrony środowiska

Streszczenie

W artykule przedstawiono metody lokalizacji nieszczelności rurociągów ciepłowniczych. Przedstawiono wady i zalety każdej z opisanych metod. Scharakteryzowano eksploatację i modernizację rzeczywistej sieci ciepłowniczej w mieście do 30 tysięcy mieszkańców na przestrzeni 10 lat. W badanej sieci ciepłowniczej przeanalizowano stopień i kategorie awarii występujących w badanej przestrzeni czasu w sieci oraz określono ich wpływ na środowisko naturalne. W artykule zbadano również oddziaływanie rożnych czynników, takich jak: ilość wody uzupełniającej, ilość ciepła do podgrzania nośnika na uzupełnienie, koszt łączny ciepła przeznaczony do uzupełnienia nośnika, zład łączny sieci oraz ilość wymian wody w systemie i jej wpływ na środowisko naturalne. Równolegle, podjęto ocenę wpływu modernizacji sieci ciepłowniczej, połączonej z jej uzbrojeniem, na zmniejszenie oddziaływania wymienionych czynników na ochronę środowiska.

Słowa kluczowe:
sieć ciepłownicza, monitoring sieci, awarie sieci ciepłowniczych, ochrona środowiska, sieci preizolowane