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Non-destructive methods for assessment of district heating pipes: a pre-study for selection of proper methods

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Abstract

Many energy companies are facing renewal of their district heating and cooling (DHC) network. However, there are no non-destructive methods to determine the performance of existing pre-insulated pipes during operation. A pre-study has led to a selection of a couple of non-destructive methods that will be further evaluated and tested in field and in laboratory. Two non-destructive methods, individually or in combination, are considered interesting for further studies. A cooling method and a method for evaluation of the temperature coefficient of resistance (TCR), which aims at using the existing copper wire in pre-insulated pipes.

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Keywords: District heating pipes; lifetime status; non-destructive methods; degradation; PUR, Cooling methods; TCR-method

1. Introduction

DHC-systems may consist of hundreds of kilometers of pipes which most likely are of different quality concerning carrier pipe, insulation, single and twin pipe. A system normally grows gradually and thereby the age and type of pipes consequently vary with time. DHC-networks have been used for decades and they expanded a lot in the 1960s in the US and Europe, the pipe types that have been used varies [1]. Pipes with for example polyurethane (PUR) insulation have been used for decades, especially in Sweden.

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Many energy companies need to renew their district heating (DH) networks. The Energy companies can measure what they produce in heat energy and what they deliver, so the heat losses for the whole network can be calculated. In Sweden, around 10% of the energy supplied to the district heating networks are lost through heat losses from the distribution pipes [2]. There is though no method to assess the status of the different parts of the piping network, in terms of local heat losses. Consequently, the desire to detect and monitor the location of potential hot spots (poor insulation) in DH networks is a significantly favourable issue for energy companies. It is favourable for many energy companies to estimate the remaining service life of pre insulated district heating pipes. The length of the pipe stretch that might need to be changed has to be long enough in order to make the excavation and change beneficial. Beneficial lengths for change depend on the thermal quality, but also on other factors like for example accessibility of the existing pipes; reasonable lengths are predicted to be in the kilometre scale. Today the time domain reflectometry method (TDR) is used for detection of moisture/water intrusion into the insulation part of the pipes. This method is well functioning for the purpose of finding suspected water leaks but not for thermal status identification of longer stretches. The European Standard EN 253:2009 states that pre insulated pipes should survive for at least 30 years at a constant operating temperature of 120˚C and new pipes should have a thermal conductivity coefficient at 50 °C (λ_{50}) ≤ 0,029 W/m·K) [3].

1.1. Single pipe with PUR insulation

A common type of pipe in Swedish DH-systems consists of an inner pipe of steel and an outer casing of Polyethylene (PE). As it is illustrated in Figure 1, there is a PUR-insulation together with two thin 1.5 mm^2 copper wires between the inner pipe and outer casing, a typical pipe product that has been used during decades. The copper wires are used for moisture detection by using TDR-method. Aging and degradation of the PUR insulation takes place due to high temperatures in the inner steel pipe (carrier pipe) and intrusion of gasses through the PE-casing pipe. Thermal properties of pre-insulated pipes, which normally are filled with PUR, deteriorate during the real operation conditions. The degradation of PUR occurs due to diffusion of gas molecules between the foam and surrounding air. In this process oxygen and nitrogen molecules penetrate from air to the foam bubbles and replace the blowing agent gases, which are mainly cyclopentane and carbon dioxide [4].

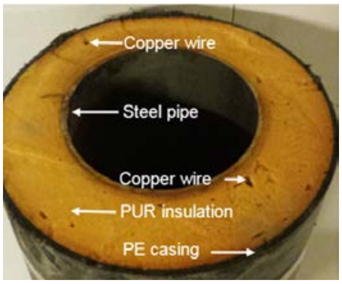

Figure 1. An old and naturally aged district heating pipe with a carrier pipe of steel, PUR foam insulation, copper wires and casing of PE.

Aging of the pipe insulation leads to higher heat losses. Temperature is the most significant factor that accelerates the aging process of insulation [5]. Therefore, when the PUR-insulation is exposed to high temperatures, thermal conductivity coefficient, λ, of insulation increases and subsequently greater heat flow (losses) is expected, based on Fourier's law (Eq.1).

$$q = -\lambda.\nabla T = -(\lambda.\frac{\partial T}{\partial x}, \lambda.\frac{\partial T}{\partial y}, \lambda.\frac{\partial T}{\partial z}) \ [\mathrm{W}\cdot m^{-2}] \quad (1)$$

Where:

q = Heat flow [$\mathrm{W}\cdot\mathrm{m}^{-2}$]

λ = Thermal conductivity [$\mathrm{W}\cdot m^{-1}\cdot\mathrm{K}^{-1}$]

∇T = Temperature difference [K]

2. Pre-study

As a consequence of the need of finding methods for assessing the status of DH networks a pre-study was conducted [6]. Several reports and scientific articles were reviewed in order to pin-point possible methods for remote detection of chemical, electrical and thermal properties of PUR after natural thermal degradation. The studied methods were limited to only non-destructive ones. The methods that have been evaluated for this purpose were ultrasonic methods, chemical analysis, electromagnetic methods, reflectometry methods, voltage response, Tan-Delta, ground penetrating radar and infrared thermography test. The suitability for applying these methods on the DH pipes was evaluated by ranking them against each other through weighting from a number of criteria, for example portability, level of consistency, inspection time, level of non-destructiveness, etc.

A modified TDR-method has been highlighted as a potential method for evaluation. The development of this type of method is on the other hand assessed to be hard and time consuming.

2.1. Non-destructive methods

As was concluded in the pre-study, an important criterion in order to find a well-functioning method is its non-destructiveness. The two methods that have been interesting to proceed with are the TCR-method, cooling method and TDR-method. A modified TDR-method will be evaluated depending on the outcome from the two aforementioned methods.

2.1.1. TCR-method

One of the tested methods, here called the TCR-method, is going to be conducted in laboratory environment with new and artificially aged pipes. Aging will be done by circulating heated oil within the pipe according to SS-EN 253:2009. The temperatures will be around 190˚C compared to the stated 170˚C, but with a proportional decrease in heating hours, approximately 200h compared to 1450h. The pipes will be placed for aging as shown in Figure 2.

Figure 2. Illustration of experimental set up for electrical resistance measurements before, during and after aging. Pipes are artificially aged by heated oil inside the steel pipe.

The method is aiming to determine a relation between the electrical resistance of the copper wires inside the PUR foam and the thermal conductivity for a specific pipe dimension. There is a difference in thermal conductivity for new and old pipes and the method is striving to see whether this change can be detected by measuring the electrical resistance in the copper wires.

For many materials, the resistivity changes with temperature, so does for copper. If the temperature interval is not too large, the resistivity is a linear function of the temperature, T, and can be expressed as in (Eq.2) [7].

$$R(T) = R(T_0).(1 + \alpha(T - T_0)) \tag{2}$$

Where:

T_0	=	reference temperature [K]
T	=	temperature of interest [K]
$R(T_0)$	=	resistivity at reference temperature [ohm]
R(T)	=	resistivity at temperature of interest [ohm]
α	=	temperature coefficient of resistivity [1/K]
α_{copper}	=	$3.9 \cdot 10^{-3}$ [1/ K]

The thermal conductivity of virgin and aged pipes will be measured by using the guarded hot pipe method according to the standard SS EN 253:2009. The standard is for homogenous pipes with polyurethane insulation and the output is a mean thermal conductivity of the insulating material. The aim is to assess thermal degradation by measuring and logging electrical resistance values during temperature drop. It is expected, that the electrical resistance drop (curve) of the copper wire during a certain temperature drop in the service pipe, will differ between a virgin pipe and an aged pipe. In specific, it will take longer for a virgin pipe to reach stationary conditions in resistance and temperature compared to an aged pipe. Finally, the thermal conductivity and the electrical resistance can be correlated by using the measured change of electrical resistance, ΔR, and the measured change in thermal conductivity, $\Delta\lambda$, for virgin and aged pipes (Eq.3). It is also possible to determine the temperature at the position of copper wire by using (Eq.4).

$$\Delta\lambda \approx \Delta R \tag{3}$$

$$T = T_0 + \frac{R(T) - R(T_0)}{\alpha.R(T_0)} \tag{4}$$

2.1.2. Cooling method

If an operating DH network is shut down for a couple of hours, there may be possibilities of analyzing the cooling time and temperature change in order to assess the thermal conductivity of the pipes. A similar method has been reported by [8] which can assess the thermal conductivity of flexible twin pipes. The flexible pipe is placed in a pool with water. Warm water (80 ˚C) is circulated in the flexible pipe and the surrounding water is colder (for example 9 ˚C), see Figure 3.

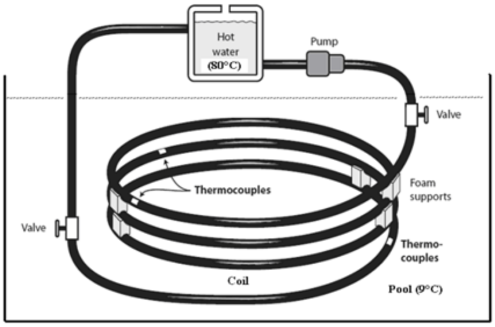

Figure 3. Experimental set-up. The coil and pool temperatures are measured by thermocouples at three positions along the pipe [8].

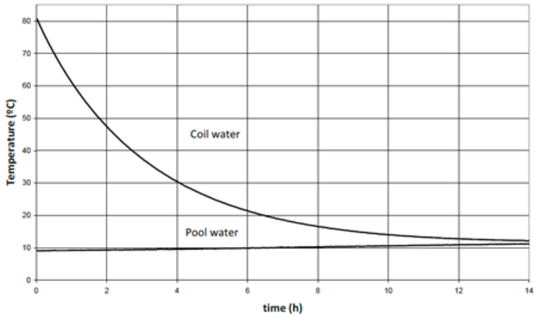

Figure 4. Measured coil water temperature and pool water temperature for a single pipe [8].

The circulated water is then stopped through valves and the cooling time and temperature are analyzed, see Figure 4. Coil water temperatures and pool temperatures are measured. The temperature decline of hot stagnant water in the pipe, immersed in cool water, depends on the thermal conductivity of the pipe. The thermal conductivity can be calculated by transient inverse calculation of the partial differential equations of heat transfer. After modification, this method may be applicable in the field, on an operating DH network with old pipes that may need to be replaced. In the case that temperature sensors can be attached on the pipes without greater effort and in a reliable way the method is worth proceeding with. Temperature sensing may also be conducted by the TCR method.

2.1.3. Time domain reflectometry (TDR)

Time domain reflectometry is an accurate non-destructive method for identifying and measuring dielectric properties of transmission and distribution lines. Within the field of district heating and cooling, the method is used to detect and locate water leakage in the insulation between steel pipe and casing. In this method a pulse generator generates incident electrical direct current (DC) signal over a conductor such as the copper wire and the steel pipe in district heating system. The measuring probe registers the reflected voltage if impedance mismatches are detected on the conductor. Impedance mismatches will cause all or part of the transmitted signal to be sent back towards the oscilloscope. The oscilloscope monitors the pulses that are generated from TDR. The distance of discontinuity can also be determined by measuring the reflection time between reflected impulse and pulse generator [9].

3. Results of initial experiments

3.1. TCR-method

Laboratory experiments of the TCR-method is ongoing and results are expected within short. In an orientating lab test a measurement has been conducted for a copper wire [1.5mm2] in a heated bath, see Figure 5.

Figure 5. Measurement of electrical resistivity in a copper wire during heating of the surrounding water.

The results indicate that the method is worth proceeding with since relatively large change in resistance values (Ω) compared to temperature can be observed, see Table 1. The experiment is made in a rough environment, meaning no stable climate. With stable climate (as in district heating pipes) and with equipment with higher resolution, every change in degree Celsius can be observed as a change in electrical resistance.

Table 1. Electrical resistance in a 6 meter long copper wire 1.5mm^2 during heating of the surrounding water.

Temperature [˚C]	Ohm [Ω]	Time after start [min]
8.0	0.060	0
16.0	0.063	9
25.0	0.065	16
35.0	0.067	24
43.0	0.070	32
50.0	0.072	41
25.0	0.065	47
23.0	0.064	55

The results indicate that the resistance interval stretches from 60-72 mΩ during a temperature raise of 42˚C. This enables the fact that for every degree Celsius the electrical resistance changes with 48 μΩ/m, for this interrogated 6 meter copper cable.

3.2. Cooling method

Field test of the cooling method for an operating DH-network is under investigation and preparation. Results are expected to be presented as there are possibilities and limitations for further development of this method.

4. Conclusion

A pre-study has been conducted from which it can be concluded that there are no existing methods that can fulfil the need regarding a tool for assessing heat losses at different parts and stretches of a DH network. Thereby, the lifetime and status of a DH network cannot be evaluated. The pre-study reveals that the most suitable existing technique that could be employed if it is further developed is the TDR-method. Two other non-destructive methods are of more interest since they appear to be easier to test; a cooling method and a TCR-method. The main advantages of these methods are that they are non-destructive. Both methods are also relatively simple to perform. The limitations differ for the two methods. All networks are built up in different ways and the accessibility for temperature measurements and possibilities for temporary shutting down parts of the network differ, therein lies the challenge for the cooling method. For the TCR-method the limitation that seems to be the most critical, is the difference in copper wire distance in relation to the heated steel pipe. Small deviations result in large temperature changes. This may be solved by evaluating longer stretches and finding a mean value for the copper wire distance. It can be postulated that a statistical approach would be suitable. This method is on the other hand assessed to be the most appropriate for brand-new pipes since all measurements will be relative to the start value. The latter is a potential solution to the problem with the copper wire distance. The cooling method is assessed to be suitable for both old and brand-new pipes. Another interesting alternative is to merge the two methods and use the TCR-method for temperature measurement during a controlled cooling of a pipe stretch. In the case that these methods can be further evaluated and developed, energy companies may have tools for making an efficient cost-benefit analysis for renewing parts of their networks.

References

[1.] Fredriksen, S. and S. Werner, District Heating and Cooling. First edition ed. 2013: Studentliteratur AB.
[2.] Berge, A., B. Adl-Zarrabi, and C.-E. Hagentoft, Assessing the Thermal Performance of District Heating Twin Pipes with Vacuum Insulation Panels. Energy Procedia, 2015. 78: p. 382-387.
[3.] SS-EN253:2009, District heating pipes – Pre insulated bonded pipe systems for directly buried hot water networks - Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene. Swedish standards institute.
[4.] Persson, C., Predicting the Long-Term Insulation Performance of District Heating Pipes, in Department of Civil and Environmental Technology. 2015, Chalmers University of Technology.
[5.] Kręcielewska, E. and D. Menard, Thermal conductivity coefficient of PUR insulation material from pre-insulated pipes after real operation on district heating networks and after artificial ageing process in heat chamber, in The 14th International Symposium on District Heating and Cooling, September 7th to September 9th, 2014. 2014: Stockholm, Sweden
[6.] Adl-Zarrabi, B. and A. Kakavand, Introduction of possible inspection methods for evaluating thermal aging status of existing pre-insulated district heating systems. 2015: Chalmers University of Technology.
[7.] Cutnell, J.D. and K.W. Johnson, Physics. 6th edition ed. 2003: Wiley.
[8.] Reidhav, C., Sparse district heating and flexible district heating pipes. 2010, Chalmers University of Technology.
[9.] Ariffin, A.M., et al. Application of time domain reflectometry technique in detecting water tree degradation within polymeric-insulated cable. in Condition Monitoring and Diagnosis (CMD), 2012 International Conference on. 2012.