Non-destructive methods for assessment of district heating pipes

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Abstract

Many energy companies are facing renewal of their district heating network. However, there are no methods to determine the thermal performance of an existing pre-insulated district heating pipe during its operation. The insulation performance of the pipes decreases gradually during time due to degradation of polyurethane (PUR) foam. The aim of our project is to find non-destructive methods for assessing the lifetime and the status of both old existing pipes and new pipes. All present methods demand some kind of excavation and interference in the network in order to assess the thermal status of the pipes, the methods determine the status of the excavated part and not the status of the network. In existing pipes, copper wires are used for detection of moisture/water intrusion into the insulation part of the pipes. The copper wires are possible to use with other measuring or evaluation techniques in order to assess thermal properties. One of the tested methods, which is based on the electrical resistance in the copper wire has been named thermal coefficient of resistance method (TCR-method). It may be used for new pipes but also for old pipes if it is combined with a cooling method. Laboratory tests have been performed both for the cooling method and TCR-method in order to develop the methods for further test in field.

1. Introduction

District heating networks (DH-networks) may consist of hundreds of kilometres of pipes which most likely are of different quality concerning carrier pipe, insulation and can consist of a single or twin pipe. A network normally grows gradually and thereby the age and type of pipes consequently vary with time. DH-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, but PUR (polyurethane) insulated single pipes are very common [1]. However, it is difficult to assess the thermal status of these pipes in an effective and non-destructive way. It would be desirable and beneficial for pipe owners if a status assessment method was found. In an early stage of this project, a literature study was conducted to see if there is any non-destructive method for district heating pipes or other purposes that can be used or modified [2]. No proper method was found but ideas for new possible methods came up [3]. The method currently applied on district heating pipes indicates only moisture leakage and is based on electrical resistance measurements between the inner steel pipes and the copper wires embedded in the PUR insulation. The measured resistance indicates whether moisture is present in the insulation. However; if it is possible to show the current thermal conductivity of the insulation material through resistance changes in the copper wire itself, then a prediction can be made regarding the thermal status of the pipe. The methods evaluated in this paper is the TCR-method and a cooling method. In this paper, the methods are individually evaluated but a combination of the two is suggested to be relevant for future field measurements. A version of the cooling method has been evaluated for flexible pipes [4].This method is based on a temporary shutdown of a part of the network and the cooling process is registered in the pipe by temperature sensors. This method, however, is difficult to implement for common district heating pipes in the field. The lack of temperature sensors makes the method incomplete for that purpose. Theoretically, however, the temperature should be possible to log indirectly by measuring the electrical resistance in the copper wire, as there is a correlation between resistance and temperature. The purpose is to develop a non-destructive method for assessing the thermal status of a district heating network. The method will be developed in a laboratory and evaluated in an active district heating network. The results from previous work [3] show that a combination of two methods, namely the TCR method and the cooling method, has the greatest potential for status assessment of existing district heating pipes. In order to combine the methods, the methods will be investigated individually in order to find if they provide the desired information.

2. Method and laboratory results for the TCR-method

The TCR method utilizes the relation between electrical resistance and temperature in the copper wire. The TCR method is primarily intended to provide with information about the temperature inside the pipe at the copper wire position. Thus, act as a temperature sensor for the cooling method. By measuring the electrical resistance in the copper wire, it is possible to calculate the average temperature of the copper wire position for the measured pipe stretch. Equations (1-3) can be used to measure the temperature [5], which can further be used to assess any altered thermal conductivity.

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

$$\Delta\lambda \approx \Delta R \tag{2}$$

$$T = T_0 + \frac{R(T) - R(T_0)}{\alpha.R(T_0)} \tag{3}$$

were T_0 [K] is reference temperature, T [K] is temperature of interest, $R(T_0)$ [ohm] is resistivity at reference temperature, R(T) [ohm] is resistivity at temperature of interest, α [1/K] is temperature coefficient of resistivity, α_{copper} is $3.9 \cdot 10^{-3}$ [1/ K], ΔR [ohm] is difference in resistivity for a new pipe versus an old pipe, Δl [W/(m·K)] is difference in thermal conductivity for an new pipe versus an old pipe.

The copper wire in a district heating pipe is not entirely straight and this affects the results of measurements. Therefore, a measurement must be performed in connection with pipe installation (if not used together with the cooling method). This measurement can be used as a reference for future measurements during the lifetime of the pipes. If a single pipe is measured during installation and later after x number of years, the method should also be able to use without implementation in the cooling method. That means that this method by itself can also be used for thermal status assessment of a new pipe.

2.1 laboratory results

A laboratory test was conducted in order to look at the relationship between temperature and electrical resistance, the copper wire in an existing district heating pipe was used during heating with the 'Guarded Hot Pipe' method (GHP method). Before test start, the copper wires were connected to one end of the tube, see Figure 1.

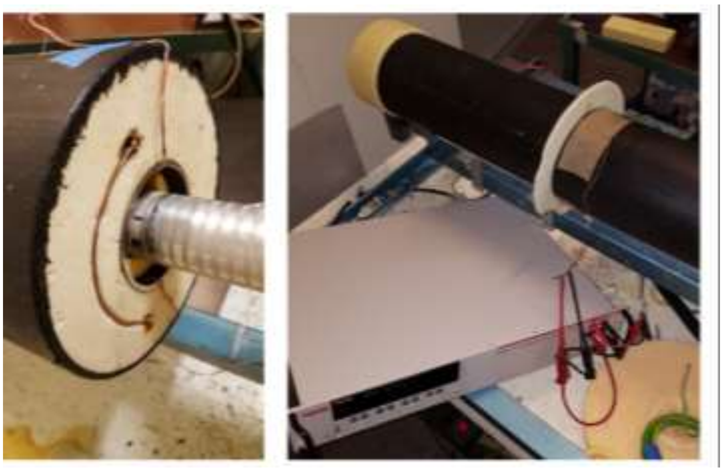

Figure 1. Test setup for resistance measurement while using the GHP method

Laboratory equipment: Micro-Ohm meter data logger (Keithley 2750), Temperature data logger, Guarded Hot Pipe Instrument: a heater with temperature sensor (Hot Water Simulation), Thermocouple and Constant Current Generator.

The test with electrical resistance measurement during heating and cooling with the GHP method gave the expected result, see Figure 2.

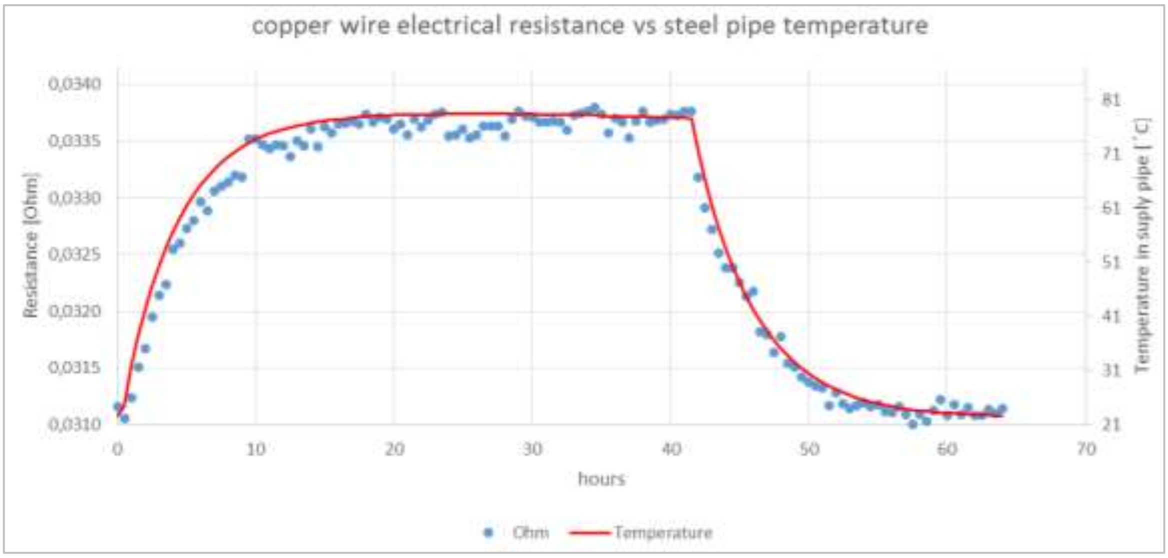

Figure 2. Steel pipe temperature (water temperature) and electrical resistance. The graph shows a clear connection between the temperature in red and the resistance in blue.

3. Method and results for the cooling method

A method for assessing heat losses in a district heating pipe network is to record temperature changes in the district heating water when the water is standing still, i.e. when the valves are closed for the investigated pipe stretch. The temperature change can be converted to the amount of energy that has disappeared from the pipe to the surrounding environment, see equation (5). With time and temperature reduction, the heat losses from the pipe can be calculated. Furthermore, the total thermal conductivity of the pipe can be calculated by the equations (6) and (7).

$$Q = \rho c * A * L * \Delta T \quad (5)$$

$$K = \frac{-C * ln\left(\frac{\Delta T_{start}}{\Delta T_{slut}}\right)}{t_{tot}} \quad (6)$$

$$\lambda = \frac{K * ln\left(\frac{r_2}{r_1}\right)}{2 * \pi} \quad (7)$$

where Q [J] is energy, ρc gives C [J/K] which is total heat capacity of water, A [m^2] is the cross sectional area of the pipe, L [m] is the length of the pipe, ΔT [K] is temperature difference, K [W/K] is conductance, t is seconds, ΔT start [K] is pipe temperature before cooling minus room temperature, ΔT finish [K] is pipe temperature after cooling minus room temperature, λ [W/(m · K)] is thermal conductivity, r_1 [m] is the steel pipe radius and r_2 [m] is the total radius.

3.1 Laboratory setup and results

Chalmers University of Technology's district heating network has been used to evaluate the cooling method. A shorter distance of 23 meters was selected for measurements. In order to evaluate the thermal conductivity of the district heating pipe, thermocouples were placed on the casing of the pipe, free in the air and in existing temperature pocket in the steel pipe on the supply pipe. The flow was closed via valves on each side of the 23 meter long pipe. The flow through the pipe was shut off for 20 hours and then the temperature of the water in the pipe was measured. Figure 3 shows the experimental setup for the test of the cooling method.

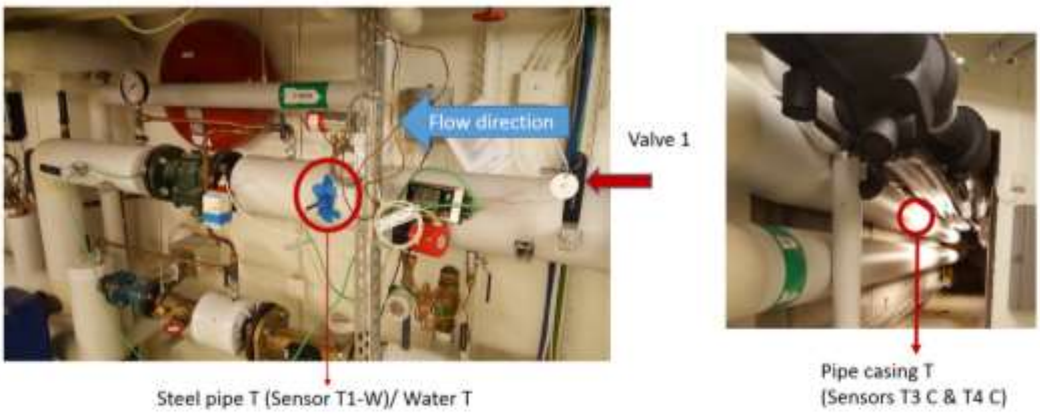

Figure 3. Experimental setup of the cooling method on Chalmers pipes. The steel pipe sensor is located to the left of the enclosed water volume and 0.3 meter to the right of the uninsulated connections.

The test of the cooling method was carried out for approximately 20 hours between 4_{th} and 5_{th} of November 2016. The result shows that the total thermal conductivity of the pipe was 43.6 mW/m·K. The lowest measured temperature with the thermocouple in the tube was 27 ºC. This temperature, however, does not represent the volume of water between the valves. Figure 3 shows that the water temperature thermocouple is located to the left of valve 1 and close to uninsulated pipe parts. When switched on, the volume of water flows to the left and the water volume between the valves passes the temperature sensor. The lower graph in Figure 4 shows how the previously enclosed water volume passes the thermocouple and forms the first temperature rise. At the plateau it is then seen that the lowest temperature was 53 ºC. Thereafter a new increase occurs when new 69 ºC water passes the thermocouple.

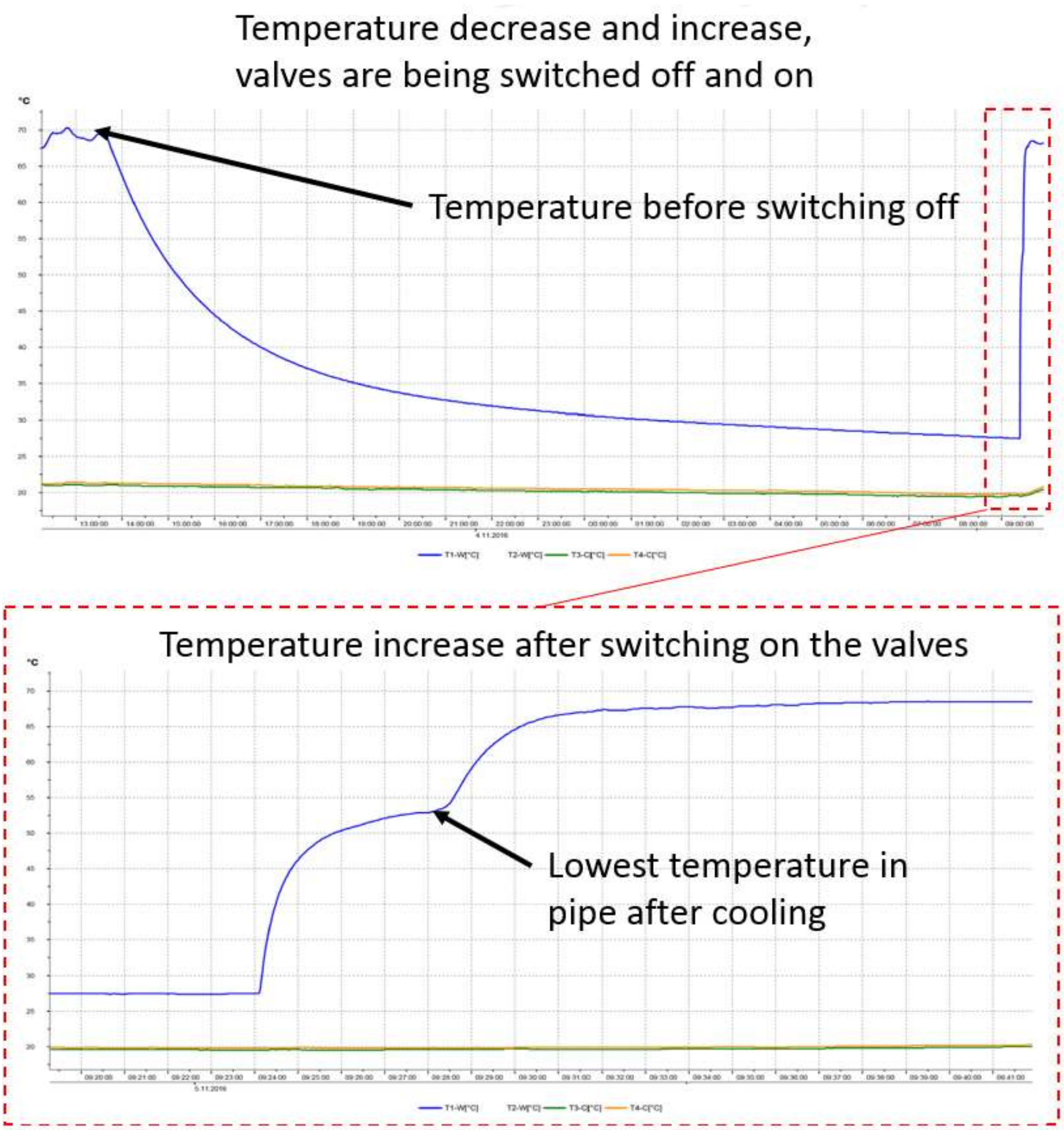

Figure 4. The top graph shows the cooling phase start at about 69 ºC. The lower graph shows the lowest temperature in pipes after cooling down and switching on, in this case 53 ºC.

To validate the result from the cooling method, a piece of insulation was removed from the test pipe in order to be tested under proven methods, namely with the Guarded Heat Flow Meter (GHFM) method. Figure 5 shows the removed insulation piece of mineral wool that was tested.

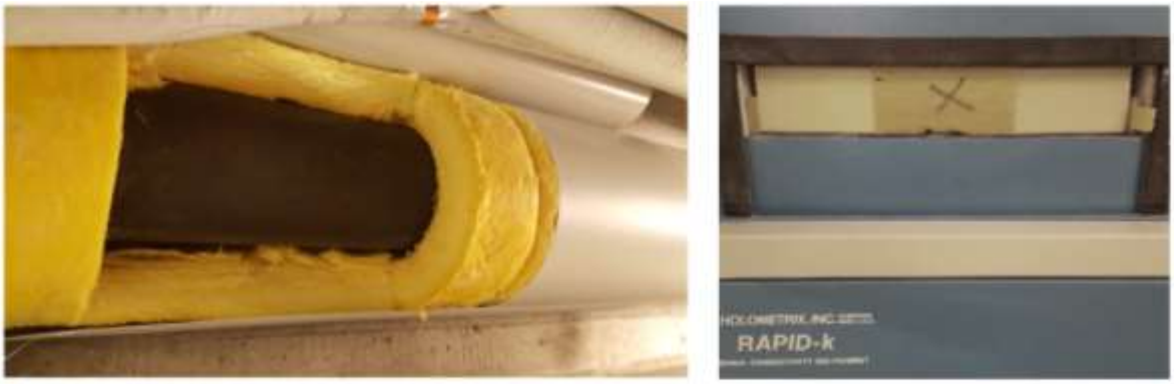

Figure 5. The picture to the left shows the pipe with the removed insulation piece. The image to the right shows parts of the removed insulation when tested using the guarded heat flow meter.

The test piece tested with GHFM was exposed to 70 °C on one side and 20 °C on the other, i.e. λ_{45}, the result gave a lambda value of 34.2 mW/m·K which can be compared with the value 43.6 mW/m·K from the λ_{41} cooling method. A lambda value of 34.2 mW/m·K is thus the absolute best insulation that can be achieved on this pipe, which is obviously impossible if looking at the pipe as a whole, including thermal bridges that always exist.

3.1 Sensitivity analysis

The result of the cooling method showed that the lambda value was 43.6 mW/m·K, this includes several types of thermal bridges, such as end losses, air pockets and insulation joints. End losses means that heat transport takes place from the pipe horizontally in the direction of the two ends of the pipe where there are non-insulated pipe parts, see Figure 3. Air pockets that occur mainly between insulation and below the steel pipes are not considered sufficiently large for convective heat transport to occur [6], see Figure 5. Because the insulation is mounted as parts, there are also horizontal and vertical joints. The lambda value for the whole pipe including all types of losses was 43.6 mW/m·K, which means that it is not comparable to the lambda value of 34.2 mW/m·K from GHFM. However; through calculations of the thermal bridges this difference was assessed reasonable.

4. Conclusion

The non-destructive methods tested in this paper have proven to work well, even if they have not yet been tested in the field. The TCR method is judged to allow temperature measurements if existing copper wire is present in the isolation of the district heating pipe. The cooling method performed on an active pipe in Chalmers properties gave a total thermal conductivity of 43.6 mW/m·K, which is considered to be quite reasonable considering the thermal bridges that existed. The mineral wool insulation from the pipe had a thermal conductivity of 34.2 mW/m·K, when tested with guarded heat flow meter. Most of the heat losses that occurred during the cooling method are not expected to occur in field measurements. The end losses in the horizontal direction were very important because the end part formed a relatively large part of the length of the pipe. In the event of a field measurement, it is likely that significantly longer stretches will be evaluated, which means that the end losses will have very little impact on total losses. In this attempt, the insulation of spliced mineral wool, a type of thermal bridge, is not commonly found in district heating pipes. Air pockets in polyurethane foam, like the air gap in this cooling attempt, are believed to have a certain, though small, effect on thermal conductivity. Since the cooling method requires some form of temperature sensor, the TCR method is recommended to be tested in field tests as a temperature sensor.

References

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