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Moisture measurements with time domain reflectometer (TDR)

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ABSTRACT

The aim of this study was to investigate the possibilities for better estimates of the extent and the seriousness of a moisture fault in a district heating pipeline. In particular, the possibilities to obtain quantitative moisture measurements using a moisture surveillance system with a time domain reflectometer (TDR) were studied. A TDR works by sending out a voltage pulse over the surveillance wire and the steel pipe used as a electric transmission line and by measuring the reflections. The measurements are usually visualised as a graph showing the intensity of the reflections vs. time. The time coordinate can be translated into a length coordinate by knowledge of the electromagnetic wave propagation velocity. Moisture will affect the dielectric properties of the PUR foam and locally change the transmission line impedance imposing reflections which will change the the graph from a dry state reference curve.

The work has mainly focused on measurements with TDR to determine the relationship between amount of moisture and the intensity of measured reflections. Studies were also made on how moisture in different locations in the pipe's cross-section affects the results. The experiments were performed on a test pipe in the laboratory designed to simulate a moisture fault.

A linear relationship appears to exist between the amount of moisture present between the surveillance wire and the steel pipe and the intensity of the reflections in the TDR curve. In principle, this makes it possible to do quantitative measurements and determine the amount of moisture from the curve. TDR measurements can accurately pin-point the location and indicate the size of the moisture fault, but the local extension of the fault along the pipe can not be determined. For all tests done, the actual length of the moisture fault can not be determined from the TDR curve. Furthermore, moisture in the outer parts of the insulation, or far away from the surveillance wire, can not be detected. Only moisture directly in between the wire and the steel pipe is visible to the TDR.

Keywords: District heating pipe, moisture, time domain reflectometer (TDR)

INTRODUCTION

Since district heating pipes insulated with polyurethane foam (PUR foam) was introduced the dominating method for detecting moisture in the insulation has been to measure the electric properties of the PUR foam between the surveillance wires and the steel pipe.

The most common system in Sweden comprises two non-insulated surveillance wires of soft-annealed copper moulded in the PUR foam parallel to the steel pipe. The easiest way to test such a system is to measure the DC resistance between one of the surveillance wires and the steel pipe or between the two surveillance wires. Moisture will affect the electrical conductivity of the foam and this method can be used to verify if there is moisture in the insulation somewhere along the pipe.

By using a time domain reflectometer (TDR) it is possible to pinpoint the location of a moisture fault. The TDR works by sending out a voltage pulse over the surveillance wire and the steel pipe,used as an electric transmission line. The reflections on the line is measured with high voltage and time resolution and is usually visualised as a graph showing the voltage change vs. time. Disturbances like moisture, variations in the distance between the surveillance wire and the steel pipe or interruption in the wire causes changes in the electrical impedance of the line [1] creating the reflections displayed in the graph. When moisture enters the PUR-foam between the surveillance wire and the steel pipe the dielectric properties of the material is changed as the dielctric constant [2] for water is far higher than for the dry insulation.

This paper is a summary of a Swedish report (Nilsson *et al*, 2005) on a study focused on quantitative moisture measurements with TDR. Other studies concerning moisture measurements in district heating pipes are reported by e.g., Andersson (2002) and Bjurström *et al* (2003).

EXPERIMENTAL

The work has focused on measurements with a TDR of type Kabel Radar 904 performed on a test pipe in the laboratory on simulated moisture faults. The test pipe consisted of two 12 m long district heating pipes, DN 65/160, with two surveillance wires, figure 1. The surveillance wires in the two pipes were coupled together to simulate a 48 m long pipe. 2 m from the end of one of the pipes, a length of 0.5 m was stripped from PUR foam, figure 2. This test space was used for simulating different types of faults.

Reference measurements were done at different temperatures before and after the PUR foam were stripped of the 0.5 m test space to find a reference curve for the following measurements. Measurements were also done to test how changes of the distance between the surveillance wire and the steel pipe affects the TDR curve.

To study how the amount of moisture and its location affects the measurements small plastic bags filled with water was used to simulate maximum amount of water at different lengths between the surveillance wire and the steel pipe, figure 3. For simulation of different moisture levels, partially water filled PUR foam was used, figure 4.

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[1] The transmission line *impedance* is a characteristic value depending on the geometry and resistive, capacitive inductive properties of wire, pipe and surrounding material.
[2]. The dielctric constant is a measure of the materials ability to store electric energy. It is 50 – 70 times higher for water than for PUR-foam.

Figure 1. Test pipe mounted on laboratory wall.

Figure 2. Space for simulated moisture faults.

Figure 3. Water filled bags. Each bag contains approximately 90 ml water, is approximately 80 mm wide and fills up the 18 mm space between the wire and the pipe.

One example of how wet PUR foam was arranged in the joint space is shown in figure 4. The foam pieces were shaped as “quarter shells”, covering one fourth of the medium pipe’s circumference, with a thickness in the radial direction of 18 mm. The picture shows two wet 190 mm long foam pieces wrapped in plastic foil arranged to a total length of 380 mm. The wet PUR pieces had a moisture content of 50 - 58 % (percentage by volume). Two dry foam pieces are placed externally. The plastic foil was used to isolate the moisture in the wet PUR foam.

Figure 4. Partially water filled PUR foam. The foam pieces are shaped as “quarter shells”, covering one fourth of the service pipe’s circumference, with a thickness in the radial direction of 18 mm. The picture shows two wet 190 mm long foam pieces wrapped in plastic foil arranged to a total length of 380 mm. The wet PUR pieces had a moisture content of 50 - 58 % (percentage by volume). Two dry foam pieces are placed externally. The plastic foil is used to prohibit electric conduction between the wire and the service pipe.

RESULTS

The reference measurements showed equivalent results before and after the PUR foam was removed from the test space. Neither did different temperatures affect the results. I.e., dry PUR foam is practically invisible for the TDR.

In the following diagrams all TDR curves starts to the left with an oscillation caused by the transition from the TDR unit's connection cable and the surveillance wire. At a distance of approximately 14 m the curve is stabilized.

Figure 5 shows the significance of the distance between the surveillance wire and the steel pipe for the resulting TDR curve. The black curve is the reference curve used in all following measurements. This curve is the result of the distance 18 mm between the surveillance wire and the steel pipe along the whole pipe's length. The red and blue curves are the result of 6 mm and 2.5 mm between the wire and the pipe at a length of 0.5 m in the test space.

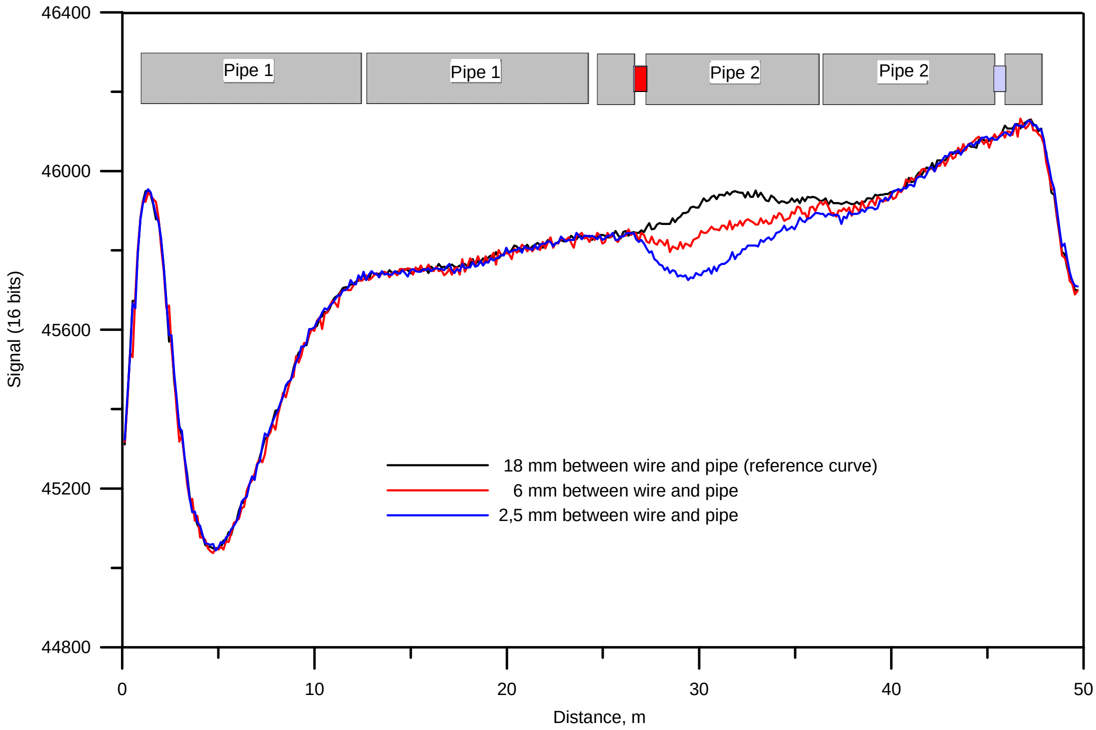

Figure 5. Different distances between surveillance wire and steel pipe in the test space.

The diagram in figure 6 shows the TDR curves from measurements with water filled bags between the surveillance wire and steel pipe.

All curves in the diagram start to diverge at a distance of 27 m, the red space in pipe 2, which equals the distance to the simulated fault. The curves' deviations from the reference curve increase more or less proportionally to the number of water bags between the wire and the service pipe. The deviation of the curve from five bags (blue curve) is approximately 5 times greater than for one bag (red curve). The results do not differ very much with respect to whether the bags are parted or grouped together. Hence, it is difficult to read out the extension of the moisture fault. The deviation from the reference curve extends approximately 15 m regardless of the actual length of the fault.

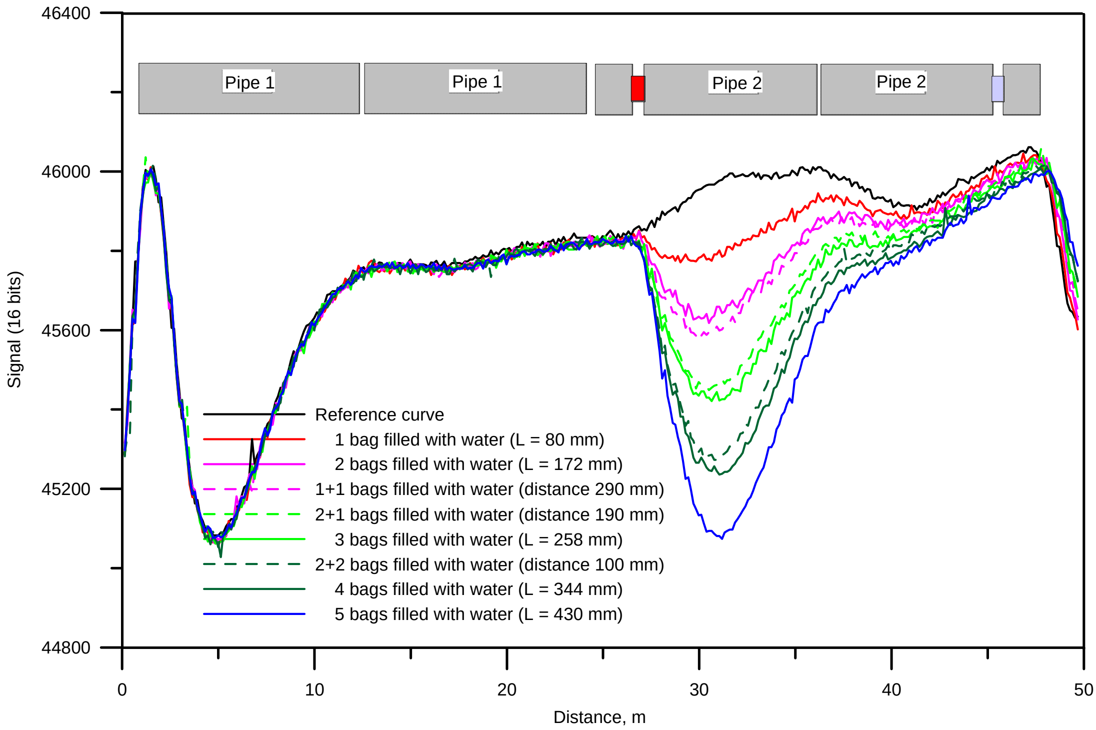

Figure 6. Water filled bags between surveillance wire and steel pipe. The solid curves represent measurements with up to five water filled bags placed as in figure 3. The dashed curves represent results from measurements where the bags were arranged in two groups. In group configuration 1+1 two bags were placed at a distance of 290 mm apart. In the group configuration 2+1 and 2+2 the bags were placed in two groups at a distance of respectively 190 mm and 100 mm.

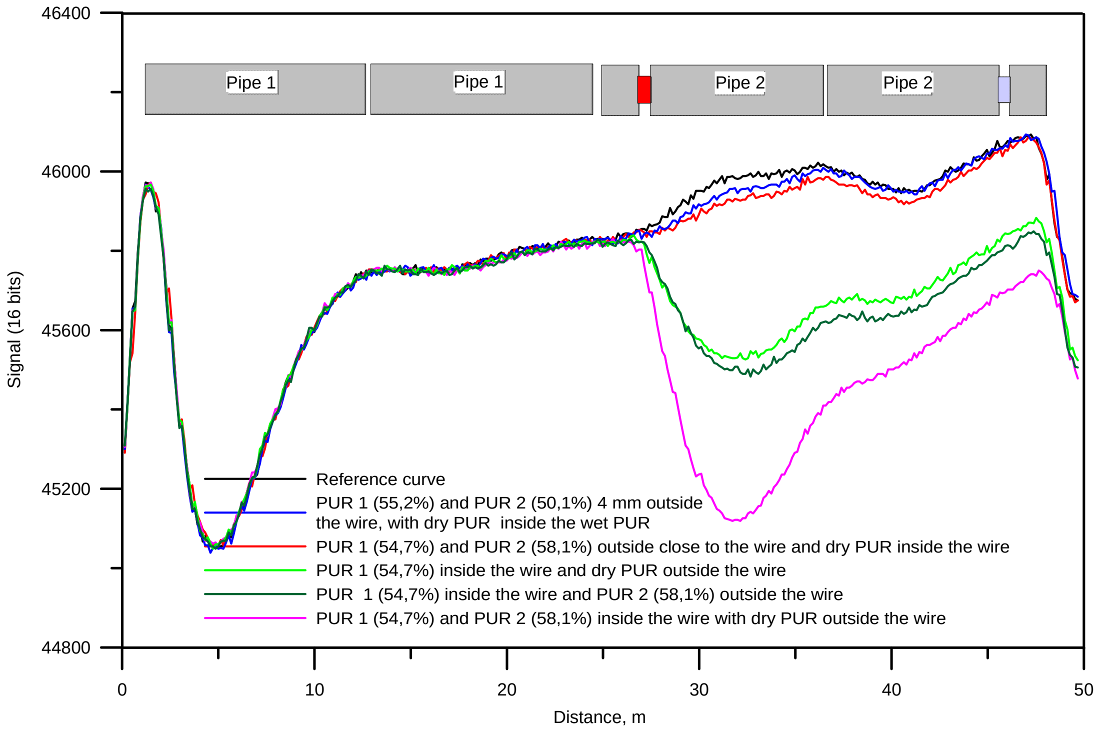

Figure 7. Partially water filled PUR-foam at different locations. The total extension of the moisture fault is 190 mm for one foam piece, and 380 mm for two pieces.

Measured results from wet PUR foam applied inside and outside the wire are shown in figure 7. The results indicate that moisture situated on the outside of the wire is hard to detect. The deviation from the reference curve is small with two wet PUR foam pieces applied outside the wire (blue and red curve). Analogously, with one wet foam piece on the inside of the wire, the difference is very small when another wet piece is applied on the outside (light green and dark green curve respectively).

The results again indicate that the deviation increases proportionally to the amount of water applied inside the wire.

DISCUSSION

To facilitate a quantitative analyse and to make it possible to compare measurements from other pipes a normalised curve should be used. A normalisation can be obtained by dividing the measured curve with the corresponding reference curve. For a dry pipe with no moisture fault the normalised curve is a straight line with the value 1. A moisture fault will appear as a value below 1. The maximum deviation is designated *peak value* and is used as a measure of the moisture indication, cf. figure 8 and 9.

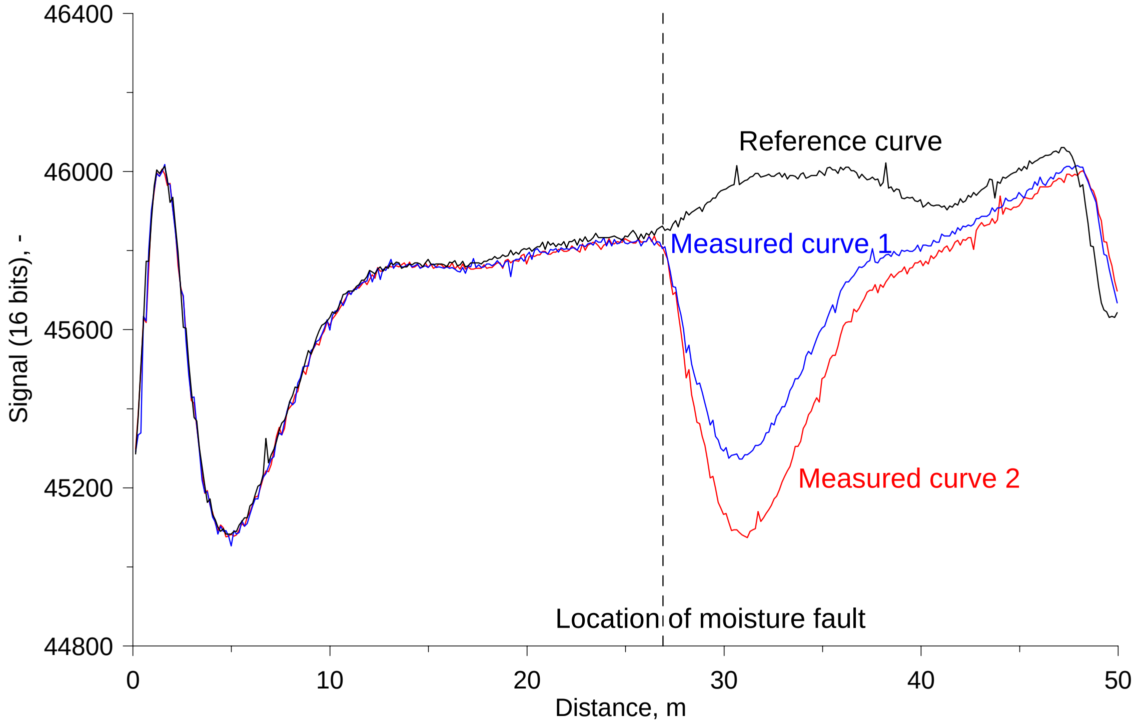

Figure 8. Measured curves and reference curve.

A quantitative measure of the amount of moisture causing the indication is needed. The measurements indicate that the TDR response depends mainly on the properties of the plane extending axially directly between the surveillance wire and the steel pipe. Therefore the area of the water in this two-dimensional plane is used as a measure of the magnitude of the moisture fault. This quantity is calculated by multiplying the moisture content in percentage by volume with the area of the two-dimensional plane between the wire and the pipe along the extension of the moisture fault.

If peak values and the quantity of water are plotted against each other, a linear correlation can be seen. The peak value is almost proportional to the quantity of water, figure 10. Some of the points for wet PUR foam do not follow the straight dashed line;

this may be caused by uncertainties regarding the actual distribution of moisture in the foam.

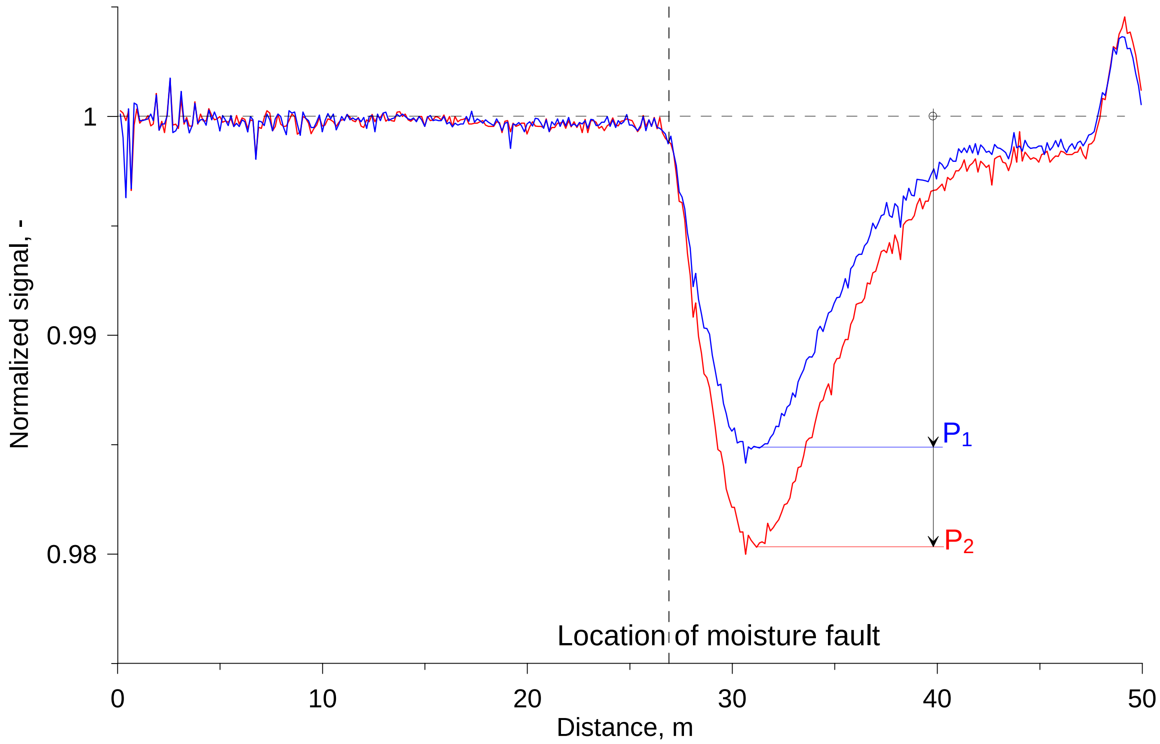

Figure 9. Quantification of moisture indication.

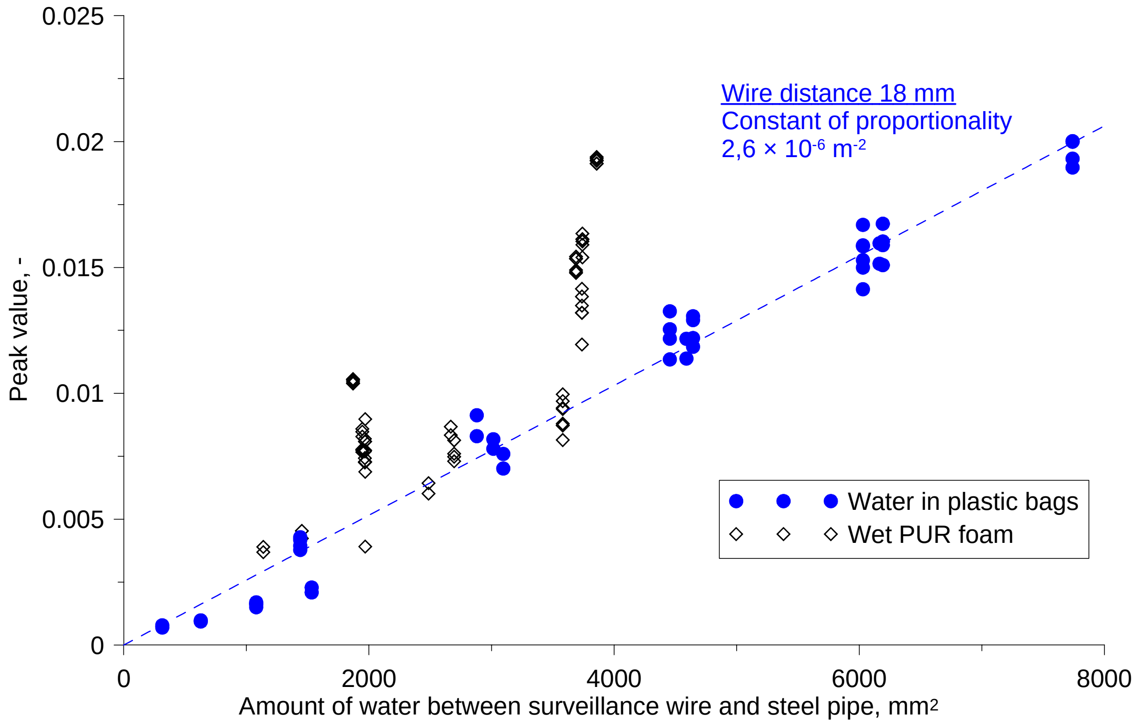

Figure 10. Relation between amount of water and measured peak value.

CONCLUSIONS

It is clear that TDR measurements carried out correctly on well documented pipes may give essential knowledge about changes in moisture conditions in the pipe. The measurements and calculations show that it is possible to obtain a quantitative estimation of the amount of moisture between the surveillance wire and the steel pipe. This makes it possible to distinguish smaller quantities from larger harmful moisture concentrations.

It is also clarified that moisture located outside the area between the wire and the pipe is difficult to detect. Furthermore it is established that the system is more sensitive for moisture located near the wire than for moisture near the pipe.

In addition it should be emphasised that it is important that the distance between the surveillance wire and the steel pipe is kept constant along the pipe. Otherwise variations in distance will appear as disturbing noise on the measured curve and make the interpreting more difficult than necessary.

ACKNOWLEDGEMENTS

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