International No-Dig 2011
29th International Conference and Exhibition

Berlin
2-5 May 2011

Paper 3B-2

# A new temperature measuring set-up to control the lining curing during the sewer renovation

Ulrich Glombitza[1] and Marcel Behlau[2]

[1] Managing director, OSSCAD GmbH & Co. KG, Friedrich Ebert Straße, 51429 Bergisch Gladbach, Germany

[2] Development engineer, OSSCAD GmbH & Co. KG, Friedrich Ebert Straße, 51429 Bergisch Gladbach, Germany

**ABSTRACT:**

Due to the limited access of the sewer the process guiding to control of the energy of hot water or steam to achieve a homogeneous curing along the liner is difficult. Today the operator gets only the current temperature value at the outer film of the sewer from point sensors (Pt-100) which are placed in the inspection chambers.

This paper will show a new temperature measuring set-up to control the lining curing during the sewer renovation by measuring the temperature without gaps along the liner. The presentation shows the principle of the fibre optic monitoring system, software engineering and software designs. Also we will present R&D results from different liner projects as well as the advantages to optimize the process guiding, to reduce the costs of renovation, to improve the quality of the liner and to improve the consumer's acceptance.

## 1. INTRODUCTION – BACKGROUND - STATE OF THE ART – MOTIVATION

There is a great demand for (gravity) sewer rehabilitation systems, both domestical and international. Pipe lining procedures are used to rehabilitate sewage systems. The liners are installed in the sewage channels via manholes, either by inversion, by feeding in using a winch, or a combination of the two. The liner is then cured using heat from hot water, steam or UV light. The liners are carefully quality-controlled, as on-site fabrication presents many challenges. Quality inspections for approval purposes are carried out after the installation. There may be quality issues after installation, e.g. local overheating (caused by the resin being too highly polymerised due to too much heat or the wrong formulation), incomplete curing (perhaps caused by water condensation in sinks along the reach) or spectral shifts in the area of operation of the UV lamps as a result of technical deterioration or incorrect operating temperatures.

Liner quality is nowadays usually carried out by visual inspection in the manhole area. If there any signs of irregularities or in order to check whether rehabilitation is required, a material probe of the cured liner is inserted through the manhole and the results are evaluated in the laboratory. In a six-year period, the Unterirdische Infrastruktur GmbH (IKT) carried out around 4,400 liner inspections. The results show that no conclusions can be drawn about the quality of the liners simply based on optical inspections in the manhole area [Bosseler].

In November 2007 OSSCAD worked together with IKT to test for the first time a fibre-optic, thermographic procedure for sewer renovation for a municipal waste water treatment plant [Diburg]. This was well-received, so OSSCAD has continued to work on developing thermographic monitoring procedures for sewer rehabilitation, for both hot water and steam curing. In January 2010 OSSCAD has been awarded the German patent for this thermographic monitoring procedure [Glombitza]. Since October 2009 OSSCAD has also been developing a state-of-the-art fibre-optic UV sensor in order to be able to offer an equivalent, reliable monitoring procedure for UV curing. This new sensor was successfully tested with a liner manufacturer for the first time in early 2011 [Röling]. This paper focuses on the fibre-optic measurement of temperature for sewer rehabilitation using heat curing.

On site, the optimal temperature for heat curing is hardly reached because the earth surrounding the old pipelines and liners is cooled to a greater or lesser extent due to seasonal weather factors, and it is not possible to estimate the influence of sinks along the reach. Monitoring the curing by making temperature checks at particular points produces unreliable and generally inadequate results, so there is still the danger that the liner will overheat or be incompletely cured. Because of this unreliability, liner manufacturers specify setpoint values of the curving temperature in order to meet the required liner quality levels. These setpoints consider the ambient liner temperature for difficulty environmental sewer behavior (not for worse case). In this way these setpoints contain a technical safety on the energy supply for the curing process, which extents the on-site working time and leads to higher energy costs. At the same time, high safety resrves premiums lead to lower profitability. The contractor has to make a unilateral decision on-site whether the levels of heat are sufficient for curing, while keeping commercial interests in mind.

This is made particularly difficult by unforeseen factors which do not necessarily come to light on the site. An example of this is the formation of condensation during steam curing. Specially in sinks the condenser water can not drain off. These sinks along the liner build thermal barriers which have a strong impact on the liner curing process. Figure (1) shows temperatures along the reach when condensation has gathered in the sinks. The processing temperature which is measured at the entry manhole with the Pt-100 sensor (shown in red) usually displays a lower temperature than the processing temperature at the exit manhole (Pt-100 shown in green). The operator can use the temperature differences at the entry and exit manhole to draw conclusions about the thermal properties along the liner and adjust the supply of heat accordingly. The condensation inside the liner makes the curing temperature much lower than in other parts of the liner. If the temperature is lower than that specified by the liner manufacturer, the liner does not cure properly and the required mechanical strength is not achieved (E-Modulus - DIN EN ISO 178).

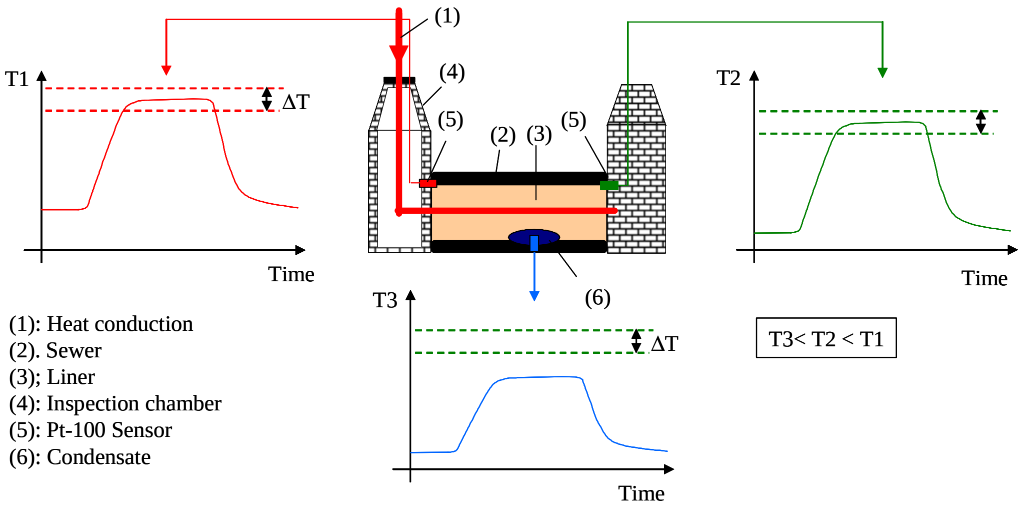


Figure 1: Diagram showing temperatures along the reach using the example of condensation gathering in sinks.

So manufacturers, contractors and operators are all keen to have an on-site monitoring procedure which can measure thermal properties along the reach accurately and in real time during the rehabilitation process. This procedure should be able to improve the process while at the same time reducing costs and should also be suitable for quality testing and approval purposes.

We will now take a look at the new methods for monitoring temperature (fibre-optic measurement, temperature data display and temperature sensor cable designs). Then we will explain the results of some sewer rehabilitation processes using thermographic images. And in conclusion we will take a look at what still remains to be done in the future.

## 2. FIBRE-OPTIC MONITORING SYSTEM, SOFTWARE ENGINEERING, SENSOR DESGINS

Principles of using fibre-optics to measure temperature: in general, temperature sensors are electronic components (thermal resistors, thermal elements, etc.) which measure temperature at a specific point. Point level sensors are unsuitable for measuring a temperature profile. Distributed temperature sensing systems (DTS) using the optical fibre as linear temperatures sensors. Temperatures are recorded using standard quartz glass fibres which are small enough to be embedded in the liner.

(1): Laser sources
(2): Anti-Stokes Detector
(3): Stokes Detector
(4): Optical temperature sensor
(5): Heat movement of the optical fibre
(6): Rayleigh scattering line
(7): Anti-Stokes scattering line
(8): Stokes scattering line
(9): Distributed temperature profile

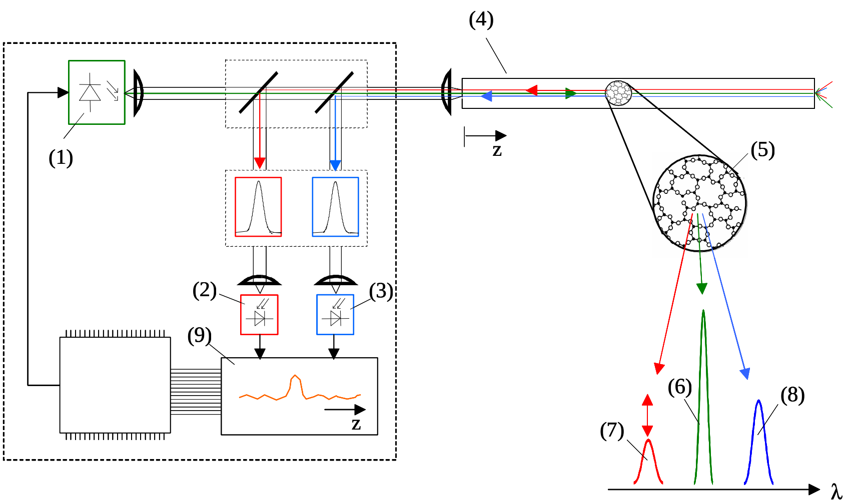


Figure 2: Set-up of a fibre-optic monitoring system

The monitoring system consists of an optical module (radar) and a fibre-optic cable as a linear temperature sensor (see figure 2). The radar works with the laser which is coupled to the sensor cable. Optical fibre cables have a very low attenuation. The minimal attenuation of optical fibre is limited by the Rayleigh scatter of the light, which is caused by the amorphous structure of the optical fibres. Heat applied to the sensor cable causes thermally-excited molecular oscillations within the glass fibre material, resulting in additional light scattering with two new spectral Raman lines (so known as Anti-Stokes Raman light and Stokes Raman light). Part of this Raman scattering light is returned from the glass fibre to the measuring device and converted into an electrical signal using photodetectors. The light intensity of the Raman scattering is proportional to the thermally-excited molecular oscillations, allowing the calculation of the temperature of the glass fibre cable. The corresponding measurement point can then be determined using Optical Time Domain Refectrometry. It is possible to locate the temperature event by measuring the time it takes for the backscattered light to return to the detection unit. The DTS measuring system works with a semiconductor laser diode and its low laser power in milliwatt (mW) means that it is not hazardous to humans or the environment. The technology has been adapted to suit sewer monitoring purposes and allows temperature to be measured precisely to ±1K (Kelvin), with a local definition of 0.5m (meter), a measurement period of 30s (seconds) and a range of up to 500m (meter).

Software engineering: The software VISCOM (Visualization and Communication) is a high-performance tool for the measurement and analysis of the curing process using thermographic images. The temperature readings are converted into RGB (red-green-blue) scale colours system and shown as a three dimension (3D) image (temperature as a function of place and time). This thermographic 3D image shows the thermal curing process as a function of the length of the reach and the time of the heat supply over the total period of the rehabilitation process in real time. The operator can select the most important points and temperature changes can be displayed chronologically. The latest local temperature graph (temperature reading as a function of the length of the measuring cable) is also displayed. An analysis tool allows recorded measurement data to be loaded and displayed as described. The analysis tool has an animation function which enables the data from the local temperature graphs to be run through in a chronological way. The following diagrams show examples of homogeneous (see figure 3, left) and inhomogeneous curing (see figure 3, right) of the liner with reference to the thermographic evaluation of the measurement data.

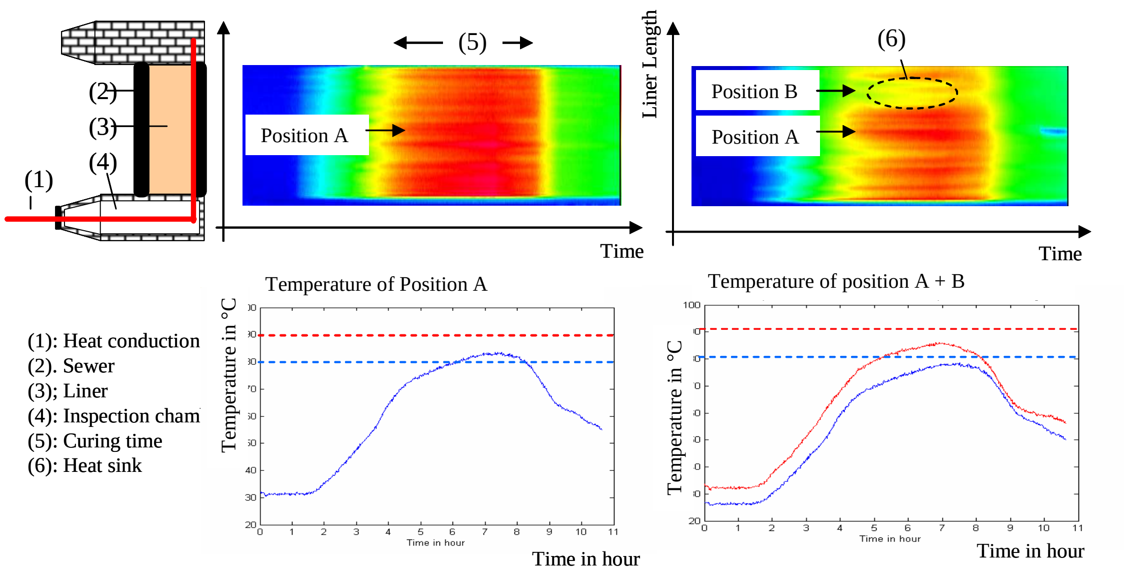


Figure 3: Example of homogeneous and inhomogeneous curing of the liner

The examples are based on temperature data of a liner rehabilitation procedure (DN 800) using hot water curing. The thermographic images show around 200 pieces of measurement data per cycle for the liner in a longitudinal direction (twelve o'clock position), with a measuring time per measurement of 30 seconds and a local definition of the analysis tool of 0.5m based on a 100m long sensor cable. The monitoring procedure shown lasts 11 hours, and the heating phase of around 6 hours can be read from the chronological temperature changes. Every thermographic image shows 264,000 temperature readings in the form of an RGB colour image. The thermal irregularities along the length of the liner are clearly shown in the (right) thermographic image, helping the operator to quickly and easily make a decision on the curing status.

Evaluation of the temperature data can also be done automatically by using software. This allows the measured section to be splitted into zones as required (in equidistant liner sections). The individual temperature readings within the zones are analysed mathematically (minimum and maximum temperatures and average temperature) and related to temperature setpoints which can be selected as required. The colours in the bar chart change according to the temperature reading. Below figure is an example of parameterisation for hot water curing. Temperatures below 56°C are below the minimum temperature required to start an exothermic reaction. These temperatures are shown in RED. Temperatures between 56°C and 63°C are sufficient to start an exothermic reaction in the resin. The chart displays these temperatures in ORANGE. Temperatures above 63°C cause the liner to cure properly. These are shown in GREEN.

Sensor designs: For fibre-optic measurements, a standard quartz glass fibre is used to record local temperature. The quartz glass fibre consists of a core with a diameter of 50µm, cladding with 125µm diameter and coating with 250µm diameter. The refractivity of the core is higher than that of the cladding of the glass fibre so that the Raman scattering is captured by the fibre and transmitted to the analysis tool.

The liner has to withstand extreme compression, drag and torque while it is being fitted to the sewer channel. The quartz glass fibre is sensitive to external mechanical forces and so must be protected accordingly. The sensor cable design is optimize for the sewer rehabilitation. The main design features of this sensor cable are shown in figure (4a). The glass fibre is fed into a small loose tube, surrounded with aramid fibres to reduce drag and protected from external damage by plastic outer sheath. The sensor cable is pre-fitted with an optic fibre connector so that they can be easily connected to the temperature analysis device. Figure (4b) shows an optic fibre connector (type E2000) with a cover which protects the ends of the sensor fibres from being contaminated on site.

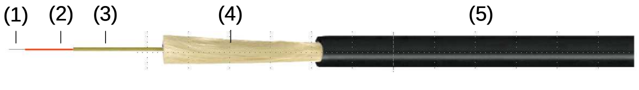


Figure 4 a) Main design features of the sensor cable
(1) Quartz glass fibre, (2) Cladding,
(3) Loose tube, (4) Aramid fibres, (5) Outer sheath

b) Pre-fitted temperature sensor cable

Temperature sensor cables are suitable for use in sewage channels and can be fitted into liners during manufacture. Feeding in of the temperature cable is initially tried out by inversion during the liner installation [Diburg]. The sensor cable is fed in along with the preliner. Figure (5a) shows the preliner with both pre-stressed sensor cables in the apex (twelve o'clock position) and base area (six o'clock position), and figure (5c) shows the sensor cable's connectors in the manhole area.


Figure 5: Feeding the sensor cable into the sewage channel.

Alternatively, the temperature sensor cable can be integrated into the liner during manufacture. The temperature sensor cable is cut to fit the length of the liner, fitted with an optic fibre connector and delivered to the liner manufacturer on a cable reel. During liner manufacture the cable can be fitted beneath the liner's protective membrane and positioned in the base, for example. After the cable has been fitted in the factory, the liner is packed with the sensor cable and transported to the site. Here it is fed into the channel. Figure 5c shows the liner with its factory-fitted sensor cable before being fed into the sewage channel.

## 3. R&D RESULTS OF LINER PROJECTS

Figures 6 to 8 show thermographic images of the three curing procedures hot water, steam and UV. Figure 6 shows the thermal curing process using hot water, measured at the apex of the liner. The first exothermic reactions take place at the end of the liner (304m on the meter scale shown), and are initially concentrated in a very small area of the liner (0.5m). After a time, other exothermic reactions occur sporadically along the length of the liner. At the beginning of the curing process, exothermic reactions are set off, with high temperatures (up to 120°C) in the old pipe and with a steep rise in temperature (~ 40°C/min). After a few minutes (between 3 and 18 minutes from the start of the first exothermic reaction), the temperature drops at a much lower rate (~1,6°C/min) and during the curing process it averages out at 60°C.

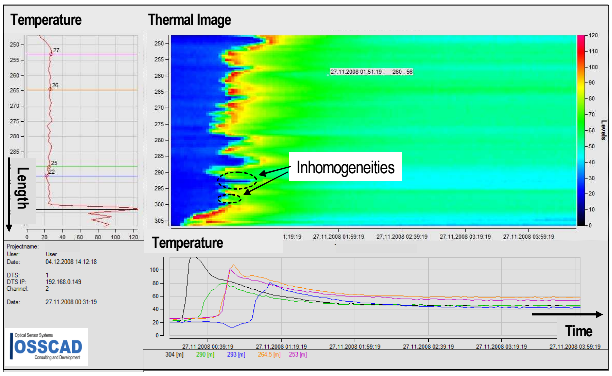


Figure 6: Examples of the display of the thermal curing process using hot water

The thermographic image shows that the temperature reading of 60°C given by the liner manufacturer is not reached all along the liner. These irregularities are shown in the thermographic images in light blue < 50°C. Extending the curing time to 24 hours allows the heat input to be increased so that the liner achieves the required mechanical strength. The following example shows the display of the thermal curing process using steam (see figure 7) during a job site in Innsbruck (Austria) where a SAERTEX-LINER (grp liner for the rehabilitation of old and corrosive sewer pipes) was installed. In this case, a big dimension egg-profile DN 700/1300 had to be renovated in the city centre of Innsbruck, where at any time a lot of traffic as well as many pedestrians are present. Therefore, the installation time had to be kept as short as possible hence the optimum choice was to install the liner under steam curing method and use of the new temperature measuring set-up with thermographic cable.

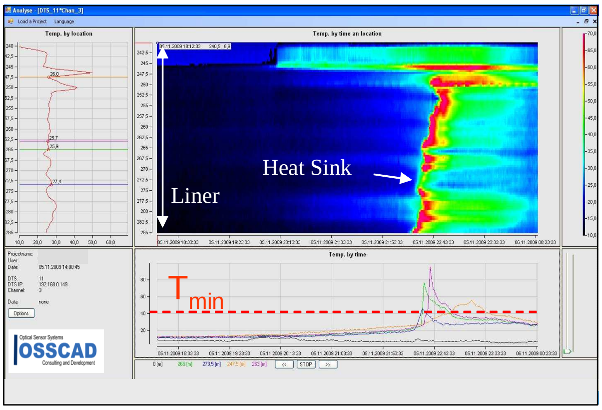


Figure 7: Examples of the display of the thermal curing process using steam

During the curing process there was an unexpected build-up of condensation during the rehabilitation procedure which prevented the necessary minimum temperature being reached at the back of the reach. The operator was able to identify these irregularities using the thermographic image and react accordingly. By extending the steam input time, the liner was then able to achieve the required strength.

The diagram in figure 8 shows the thermographic record during UV curing. The temperature on the outer skin of the liner changes independently of the draw rate of the lights. If the temperature is too high it can cause heat damage to the liner material. In order to monitor the temperature on the outer skin of the liner, a temperature sensor cable was fitted in the apex of the liner and the temperature was measured using fibre optics.

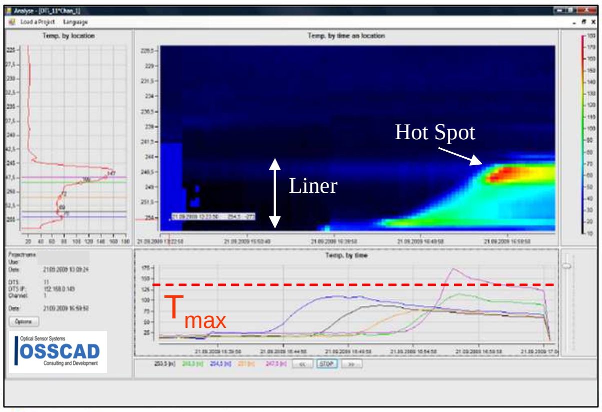


Figure 8: Examples of the display of the thermal curing process using UV light.

The different temperature increases at different times shown in figure 8 correspond to the draw rate of the lights. Only low temperatures are reached if the lights are drawn slowly. If the lights stay too long in one place then the inner coating of the liner is likely to burn. This shows the hot spot at the end of the liner. The hot spot temperature displays a reading of 175°C and exceeds the manufacturer's maximum permitted temperature. These findings allow the draw rate and the number of lights to be optimised.

## 4. Summary and Outlook

The development of fibre-optic temperature measurement means that the thermal properties along the reach can be measured in real time during the sewer rehabilitation process. The main advantages of fibre-optic sensors as compared to electronic sensors are the complete measurement of temperature along the reach and the immunity to electromagnetic disturbances during the works.

This innovative technology has been successfully used for curing processes using hot water, steam and UV light. For liners which are fed in using a winch, the sensor cable can be fitted in the liner during manufacture so that there is no installation work to do on site. For liners which are installed using inversion, the sensor cable is relatively simple to feed in.

The development of thermographic recording and zonal display makes it possible to order the readings in a chronological and spatial way in relation to the liner construction and heat input. The thermographic image allows thermal irregularities to be easily identified and countermeasures can be taken in relation to the heat input during the liner rehabilitation process.

If the minimum temperature specified by the liner manufacturer is not achieved along the sewer reach, the operator is alerted to this so that he can extend the heat input as required. This means that the rehabilitation can be successfully carried out using fibre optic temperature measurements, even under the most difficult site conditions.

If the minimum temperature is reached earlier than expected, then the safety premium is avoided and the length of the heat input is reduced. In this way, energy costs and site operation expenses can be significantly reduced, along with the amortization period of the temperature monitoring system.

The next R&D step is the technical integration of the evaluation setup in the process control of the test vehicle to monitor the lining curing automatically by using the fiber optic temperature systems.

This fibre optic, thermographic recording of the curing process also provides the customer with a proof of quality and will serve to make pipe liners more widely-accepted in the near future.

## 5. REFERENCES

Bosseler , B., Abnahme von Liningmaßnahmen - Materialnachweise und Bewertung der Linerqualität, IKT Institutes für Unterirdische Infrastruktur, BMBF Abschlussbericht, März 2009

Diburg, B., Bosseler, B., Glombitza, U., Temperaturmessung bei Kanalsanierungen unter Einsatz von Schlauchlinerverfahren, Praxisanwendung bei einem warmwasserhärtenden Nadelfilzliner in Recklinghausen, bi UmweltBau, Kongressausgabe Deutscher Schlauchlinertag, Pforzheim, April 2009

Glombitza, U., Verfahren zur ortsaufgelösten Temperaturmessung in einem Rohr- oder Kanalsystem Deutsches Patent, DE 10 2007 042 546, Januar 2010

Röling, M., A new UV sensor method for sewer renovation, International No-Dig 2011, 29th International Conference and Exhibition, Berlin, 2-5 May 2011