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INNOVATION IN CORROSION MONITORING IN SEWERS

USE OF NOVEL PHOTONIC SENSORS FOR HUMIDITY MEASUREMENTS IN GRAVITY SEWERS

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ABSTRACT

Humidity plays a key role in microbiologically induced corrosion of concrete gravity sewers. Minor reductions in humidity can reduce corrosion rates. No reliable long-lived (>1 week) humidity sensors are available, thus limiting the development of useful models to better manage corrosion. This paper describes the successful evaluation of purpose-built photonic sensors for five months in the sewer. Survival of the photonic sensors in this environment demonstrated their suitability for longer-term sewer monitoring. The use of photonic sensors provided on-line, long term, continuous humidity data in a way that was not possible in gravity sewers prior to this study.

INTRODUCTION

Sydney Water's current Sewer Rehabilitation Program costs about A$50m annually. The program mainly relies on chemical addition to minimise hydrogen sulphide (H2S) transfer from the wastewater to the sewer air, and ventilation. It has been developed based through collaborative and in-house research (Wells et al., 2009; Joseph et al., 2002; Wang et al., 2013; Gonzalez el al., 2014). Determining corrosion rates of concrete sewers remains a research gap. Determination will enable prediction of the end-of-service-life of sewers and, more selectively identify where to carry out sewer rehabilitation.

The 2008-2013 collaborative Australian Research Council Linkage Optimal Management of Corrosion and Odour Problems in Sewer Systems identified that humidity plays a fundamental role in the conversion of H2S into sulphuric acid and that potentially minor reductions in humidity can reduce corrosion rates. The air within the gravity sewer has high humidity (typically above 90%) and variable concentrations of gaseous H2S and biofouling material. Such an aggressive environment makes the continuous measurement of humidity difficult.

Accurate and long term humidity measurements will enable a quantitative correlation between allowable H2S in sewer air and acceptable corrosion rates ≤ 0.5 mm/year. Our experience using commercially available electrical sensors has demonstrated that they typically fail after around one week in our gravity sewers. This has limited the development of a useful model to better understand and inform management of corrosion. Therefore, the influence of humidity on the rate of corrosion of sewer concrete is over-looked.

This is the key driver to trialing newly developed humidity sensors that provide on-line, long term, continuous humidity data in the aggressive environment of gravity sewers (Alwis et al, 2017). This paper describes the development and performance of photonic sensors with specialised, tailored coatings designed to operate under highly biofouling and corrosive conditions.

EXPERIMENTAL

Optical Fibre Sensors Description

The Fibre Bragg Grating (FBG)-based techniques lie at the core of the sensors constructed for this application.

The glass fibres used for the manufacture of the photonic sensors were grated followed by coating with the photosensitive polyimide. The sensors were manufactured with two gratings in series to detect both humidity and temperature. The photonic sensors (Figure 1) were packaged in two polymeric materials (epoxy resin or polyether ketone, PEEK) to maximise their durability and minimise biofouling.

The response of the sensors was evaluated using a commercial Fibre Bragg interrogation system for multi-wavelength analysis of the sensors response. The calibration of the sensors was carried out by placing them in contact with air that had known relative humidity in a closed container. Calibration was carried out prior to installation in the sewer air and after five months exposure. For comparison, a commercially available humidity sensor was also installed in the sewer.

Sensors Fabrication

The photosensitive sensors used in this study were manufactured by City, University of London (CUL) and their collaborators. CUL has carried out extensive research over the last 25 years on both fundamentals and development of photonic sensors to be used in industrial applications (Grattan, 2013).

Therefore, the study reported here underpins a body of research carried out by CUL in the development and application of photonic sensors (Alwis et al., 2017); Alwis et al., 2013a); Alwis et al., 2013a; Alwis et al., 2013b; Bremer et al., 2014a, Bremer et al., 2014b; Sun et al., 2012)

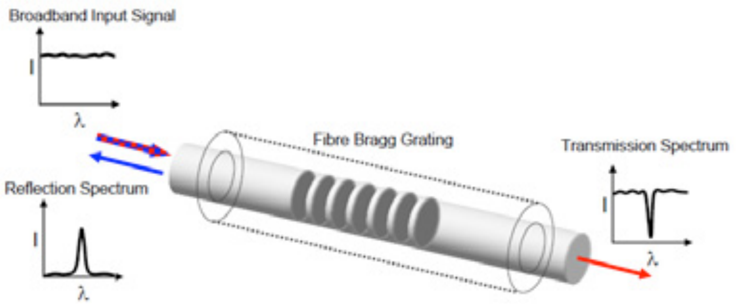

Figure 2. Diagram describing the mechanism of Fibre Bragg Grating in photonic sensors

Fundamentals of Photonic Sensors

Operation of the FBG-based humidity sensor is based on the swelling of a moisture sensitive polymer polyimide (PI) coated on the sensing element. The expansion of the coating layer, as a result of moisture absorption, induces a secondary strain effect on the polymer-coated FBG, causing the optical fibre to stretch. A low energy laser beam is sent into the fibre containing the sensors, where a particular wavelength from each FBG sensor will be reflected back.

The reflected wavelength depends on the grating period which varies with the expansion of the fibre due to moisture absorption in the coating and/or thermal effects. The wavelength variation indicates the RH levels in the sewer environment which can be calculated by the calibration data for each sensor. Any temperature induced wavelength shift in the RH sensors will be “decoupled” using the information from the wavelength shift of the bare grating (uncoated). Thus, any strain or temperature change applied to the sensing element perturbs the effective refractive index and the period of the FBG, consequently causing the Bragg wavelength to shift (Figures 2 and 3).

The FBGs used as the basis of the humidity sensors were written into the fibre at specific, known wavelengths of 1558.8 ηm, 1552.9 ηm, 1559.4 ηm and 1558.8 ηm. These wavelengths are convenient for available laser sources and used with commercial interrogation systems.

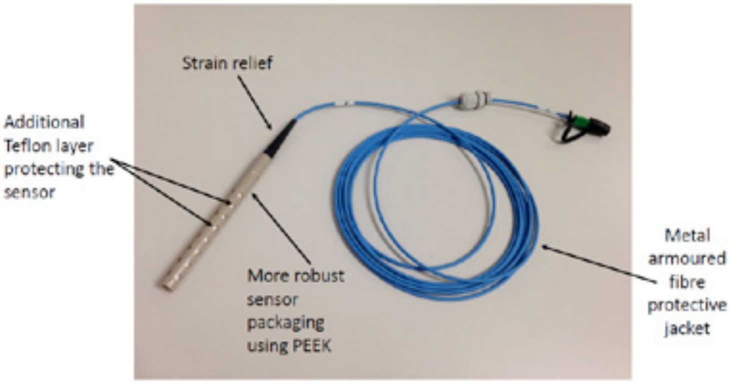

Figure 1. Close up photograph of photonic sensor, with PEEK packaging, used in this study.

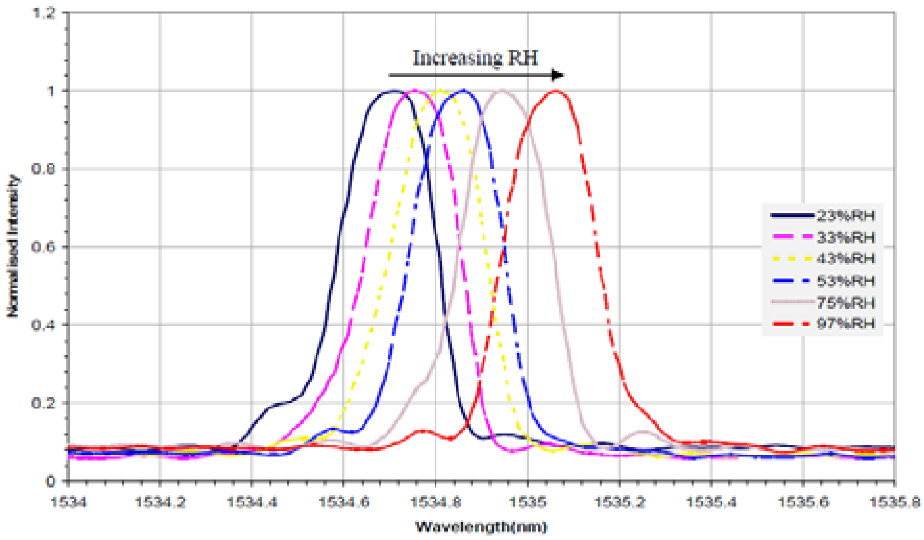

Figure 3. Reflection spectra of PI coated FBG sensor at different humidity levels.

The sensors were temperature compensated with an uncoated, and therefore humidity-insensitive, set of FBGs that were written at wavelengths of 1540.4 ηm, 1543.6 ηm, 1542.4 ηm and 1542.7 ηm. This arrangement allowed each of these wavelengths to be easily differentiated by their primary wavelength characteristics.

The multiple PI coatings on the FBGs were prepared in-house using a dip-coating system that was used to create the multilayers needed. Coatings are built up from multiple layers of the polymer material which is applied and then baked between each layer. The humidity sensors were packaged in either epoxy resin or PEEK to provide durability in the aggressive environment.

The humidity sensors were evaluated in situ to examine their durability, time response and stability over 5 months.

TESTING SITE

The experimental program was carried out in the head space of a balancing tank that is in line between the building wastewater from Sydney Water's Parramatta head office and the on-site wastewater treatment plant (Figures 4 and 5).

Figure 4 shows the photonic sensors and one commercially available electrical sensor used for comparative purposes. The experimental set up also incorporated one sensor (OdaLog) for continuous monitoring of both gaseous hydrogen sulphide and temperature.

RESULTS AND DISCUSSION

The results indicated that the photonic sensors produced strong dynamic responses and accurately recorded the high humidity levels (between 97 and 100% RH). Furthermore, in two cases where the humidity was rapidly lowered by removing them for exposure to the ambient air, the sensors rapidly responded and measured ~100% humidity when replaced in the overhead tank. The gaseous hydrogen sulphide concentration typically varied during the day between 5 and 130 ppm by volume.

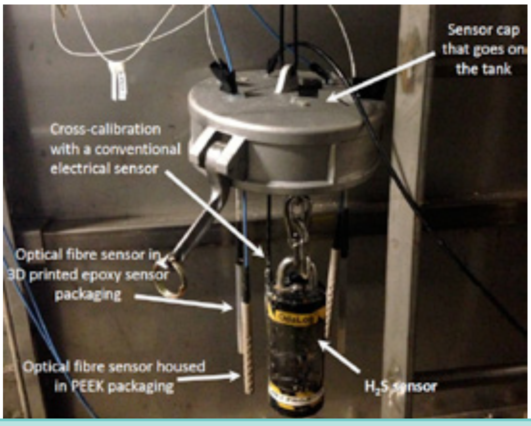

Figure 4. Sensors set up to monitor the sewer air. It includes photonic and conventional humidity sensors and one hydrogen sulphide sensor.

Figure 5. Installation of sensors set up in sewer.

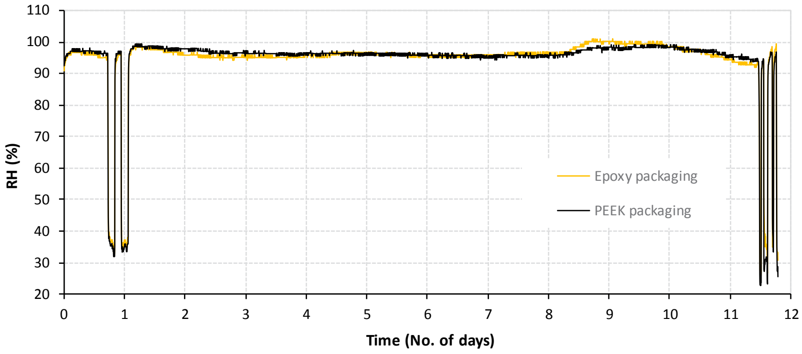

Figure 6. Performance of sensors with different polymeric packaging.

The temperature of the gas phase was around 20-23 degrees during the day and night.

Thus, the sensors showed their dynamic capability as they could respond to drastic increases and decreases in humidity. The results showed that the thinner coating takes less than 15 minutes to saturate while thicker coatings take nearly an hour for saturation. However, the sensitivity of the thicker coating is approximately more than 2.5 times that of the thinner coating.

Depending on the application, it should therefore be possible to select the coating thickness to achieve faster response or higher sensitivity. Thinner coatings for rapid response are more suitable for this study.

By comparison, the commercially available electric humidity sensor took longer to saturate. Also, after saturation was reached, the time to respond was longer. This is probably due to condensation on the sensing component of the electrical humidity sensor.

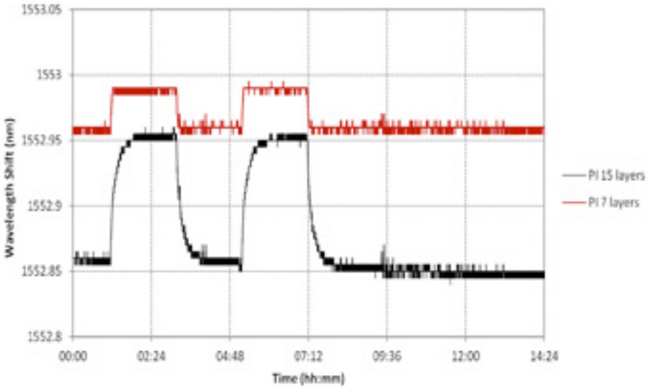

Figure 7. Effect of the thickness of the humidity sensitive polymer on sensor response.

Furthermore, visual observations of the photonic sensors indicated that the aggressive and biofouling sewer conditions had only minor impact on the physical integrity of the photonic sensors after 5 months.

The data shown were measured every 15 minutes over a period of four weeks.

Figure 8. Sensors after 5 months in the sewer showing minimum biofouling (Left to right: Epoxy packaged sensor, conventional electrical sensor, PEEK packaged sensor, hydrogen sulphide sensor).

At the end of the four weeks the photonic sensors were left in the sewer, experiencing the same harsh conditions, for four further months.

At the end of that time (a total of five months), the photonic sensors were removed and examined and re-calibrated in the laboratory at four known relative humidity levels.

This assessment of the calibration carried out in the laboratory after the sensors were removed from the sewer, after the five months exposure, showed the performance of the photonic sensors was unchanged.

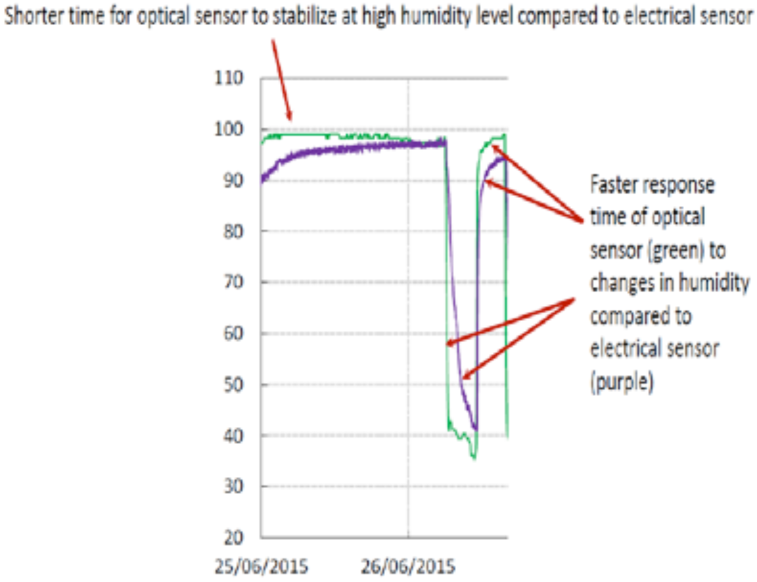

Figure 9. Detailed response time comparison between the photonic and electrical sensors.

This demonstrated that the integrity of their performance had been maintained over the five months of exposure. Further work is underway to measure relative humidity continuously with sensors of this type thus and to verify their long-term performance.

This is attributed to the selection of suitable polymeric packaging that was virtually unaffected by the biofouling environment (Figure 8).

Comparison Between Photonic & Electrical Humidity Sensors

The response time of the electrical sensor is much longer than that of the photonic sensor. The shorter response time of the photonic sensors, as well as the durability of the packaging design protecting the sensors, are the major advantages for humidity monitoring in gravity sewers (Figure 9).

CONCLUSION

This is a significant innovation in photonic sensors that they can now be used in these “dirty” environments. This has also allowed in-situ long-term monitoring under conditions where current technology fails.

This study has shown that photonic sensors are a realistic alternative to current electrical sensors to monitor relative humidity in the range where hydrogen sulphide is converted into sulphuric acid.

The ability of photonic sensors to survive in the aggressive sewer environment demonstrated their suitability for longer-term sewer monitoring over current monitoring options. This has not been possible before.

The use of photonic sensors, as part of Sydney Water’s Corrosion and Odour Strategy, will improve the monitoring of humidity and help optimise ventilation. It will also provide valuable information for the design and management of future sewer systems.

The information generated will also be used to refine the predicted corrosion rate model under different humidity levels.

This collaborative project has now been expanded into the Australian Research Council Linkage project “Putting Photonics into Sewers” that will run between 2017 and 2019 with Macquarie University, CUL and Sydney Water.

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Dr Heriberto (Heri) Bustamante did his PhD at Imperial College (London) and is Principal Scientist Treatment in Sydney Water. Heri has more than 30 years of experience in industrial research in various industries. Heri has pioneered the introduction of photonic sensors in Sydney Water to manage sewer corrosion by starting collaboration with City, University of London and the Edinburgh Napier University. This collaborative project has now been expanded into the Australian Research Council Linkage project “Putting Photonics into Sewers” with Sydney Water, Macquarie University and City, University of London.

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Professor Kenneth T. V. Grattan joined City, University of London in 1983 after five years at Imperial College, London and has been undertaking research in novel optical instrumentation, especially in fibre optic sensor development for physical and chemical sensing. The work has led into several fields including luminescence-based thermometry, Bragg grating-based strain sensor systems, white light interferometry, optical systems modelling and design, and optical sensors for water quality monitoring. The work has extensively been published in the major journals and presented at international conferences. Professor Grattan is a Fellow of the Royal Academy of Engineering in the UK currently is the Dean of the City Graduate School at City, University of London.

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Louisa Vorreiter has over 30 years of experience in many aspects of the wastewater system and environmental impacts. Louisa is currently a Service Planning Lead in asset strategy with Sydney Water and is the program manager for the development and implementation of Sydney Water's integrated corrosion and odour strategy.

José González has over 28 years of experience. He has conducted field work and laboratory analysis ranging from to trace organics to trace metals. He has developed test methods and sampling/monitoring techniques, prepared experimental plans and designed and conducted field investigations. Through his involvement in developing and implementing Sydney Water's Corrosion and Odour Strategy since 2007 he has applied and increased his knowledge of wastewater systems and processes and their environmental impacts. He currently works in the Treatment and Process Management group of Sydney Water.

REFERENCES

Alwis, S.M., Bustamante, H., Roth, B., Bremer, K.,Sun, T., Grattan, K.T.V. (2017) Evaluation of the durability and performance of FBG-based sensors for monitoring moisture in an aggressive gaseous waste sewer environment, Journal of Lightwave Technology, 35(12). DOI: 10.1109/JLT.2016.2593260

Alwis, L., Sun, T., & Grattan, K. T. (2013a). Design and performance evaluation of polyvinyl alcohol/polyimide coated optical fibre grating-based humidity sensors.. Rev Sci Instrum, 84(2), 025002. doi:10.1063/1.4789768

Alwis, L., Sun, T., & Grattan, K. T. V. (2013b). Optical fibre-based sensor technology for humidity and moisture measurement: Review of recent progress. Measurement: Journal of the International Measurement Confederation, 46(10), 4052-4074. doi:10.1016/j.measurement.2013.07.030

Bremer, K., Meinhardt-Wollweber, M., Thiel, T., Werner, G., Sun, T., Grattan, K.T.V. and Roth, B. (2014a). Sewerage tunnel leakage detection using a fibre optic moisture-detecting sensor system. Sensors and Actuators, A: Physical, 220, pp. 62–68. doi:10.1016/j.sna.2014.09.018

Bremer, K., Wollweber, M., Guenther, S., Werner, G., Sun, T., Grattan, K. T. V., & Roth, B. (2014b). Fibre optic humidity sensor designed for highly alkaline environments. Proceedings of SPIE - The International Society for Optical Engineering, 9157. doi:10.1117/12.2059637

Gonzalez, J.E., Kraakman, N.J.R. Sydney Water's Corrosion and Odour Management tool. Water Journal, 65-71, Jun 2014

Grattan,K.T.V.(2013) www.youtube.com | watch?v=gJG6I0J7d4Q

Joseph, A.P., Keller, J.,Bustamante, H., Bond, P. (2012) Surface neutralisation and H2S oxidation at early stages of sewer corrosion: Influence of temperature, relative humidity and H2S concentration. Water Research, 46, 4235 – 4245.

Sun, T., Grattan, K. T. V., Srinivasan, S., Basheer, P. A. M., Smith, B. J., & Viles, H. A. (2012). Building stone condition monitoring using specially designed compensated optical fiber humidity sensors. IEEE Sensors Journal, 12(5), 1011-1017. doi:10.1109/JSEN.2011.2163504

Wang, Y.C., Nobi, N., Nguyen. Use of Integrated Sewer Network model to develop Corrosion and Odour Management Strategy, Ozwater 13, Perth, WA, Australia

Wells, P.A., Melchers, R.E., Bond, P. (2009) Factors involved in the long term corrosion of concrete sewers,, Australian Corrosion Association Conference, Coffs Harbour, Australia