TAKING CONTROL OF ODOURS AND CORROSION IN SEWERS

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ABSTRACT

Optimal corrosion and odour management has been hindered by limited understanding of several key in-sewer processes contributing to the problems, and the lack of tools and reliable technologies to support strategic decisions and cost-effective sewer operations. A major step forward to fill the above gaps is being taken in Australia with a $20mil collaborative research project funded by the Australian Research Council (ARC) Linkage Program, 11 water industry partners and 5 university partners. The project is called the Sewer Corrosion & Odour Research (SCORe) Project.

In this paper, the state-of-the-art knowledge and practice based on both published and grey literature is reviewed and key knowledge gaps and challenges to be addressed in the SCORe Project are identified. Some of the early findings from this initiative are presented.

INTRODUCTION

Sewer corrosion and odour problems are spread worldwide, particularly in countries with warm climate. It is estimated that concrete sewer pipes in many areas of Australia are being corroded at an average rate of 1-3 mm per year. Internal surveys by several major water utilities in Australia show that the abnormally fast depreciation of assets and the mitigation of corrosion and odour problems are costing the Australian water industry hundreds of millions of dollars a year. The operations of sewer systems are experiencing significant changes at present, posing further challenges to corrosion and odour management. Restricted water use in many areas caused by climate change results in considerably reduced flow within the sewer systems. This has resulted in more concentrated sewage and increased hydraulic retention time in sewers. Also, the changing demographics within major cities have caused concentration of commercial and industrial discharges in specific areas resulting in significant impacts on sewage characteristics.

Control of corrosion at an acceptable rate and odour management requires a good understanding of key in-sewer physical, chemical and biological processes to support strategic decision-making, and reliable tools and technologies to enable cost-effective sewer operations. The last comprehensive compilation of knowledge on odour and corrosion in sewers in Australia was prepared in 1989 under the title “Hydrogen Sulfide Control Manual” (MMWB, 1989) referred to in this document as the “1989 H₂S Manual”. Several key knowledge and technology gaps have been identified which hinder the optimal management of sewer corrosion and odour problems. These challenges should be addressed through the use of multi- and inter-disciplinary approaches that encompass material sciences, microbiology, chemistry, advanced instrumentation including sensor technologies, as well as mathematical modelling, among others. It is also essential to achieve effective integration of field investigations and laboratory studies. Strong partnership and collaborations between researchers and industry are critically important for success. Integration of this knowledge with a strategic set of tools will be the key challenge to improve the management of sewer systems.

In an effort to address these challenges, most of the major water utilities in Australia are jointly funding along with the Australian Research Council (ARC), a major project, the Sewer & Corrosion & Odour Research (SCORe) Project which started in late 2008 and will run for five years with a total budget of around $20 million.

The project comprises four themes, which are:

- Theme 1 - Corrosion processes,
- Theme 2 - Gas phase technologies,
- Theme 3 - Liquid phase control, and
- Theme 4 - Knowledge management.

Nine inter-linked subprojects (SP) have been designed under these themes, each has distinctive foci and is being undertaken by a dedicated research team who are located at one or more research centres around Australia. An overview of the project design is shown in Figure.1 – An Overview of the SCORe Project.

The SCORe Project is approximately halfway through but is progressively delivering outcome for application by the Water Industry. Feedback is being provided to industry partners on a quarterly basis and a web portal (www.score.org.au) has been established to make this information readily available.
IDENTIFICATION OF KNOWLEDGE GAPS

The fundamental processes of odour and corrosion occurring in sewers as presented in the 1989 H2S Manual are basically unchanged as shown in Figure 2 – The Sulphide Corrosion and Odour Problem which has been reproduced from the 1989 H2S Manual.

However there are many practical questions where there is inadequate fundamental knowledge to provide robust solutions to water practitioners including the following:

- **Corrosion Processes & Control:** The estimation of the corrosion rate and the life expectancy of pipes are very difficult to predict and are almost entirely based on empirical data about the past performance of pipes under similar conditions.

- **Liquid Phase Technologies:** A lack of understanding of the chemical and biochemical transformations that occur in wastewater and the impact of variables such as flow velocity, sediments, changes in wastewater composition. This makes it difficult to predict the impact of chemicals commonly used to control H2S in sewers such as O2, NO3-, Mg(OH)2, FeCl3, etc. Without closing these knowledge gaps it is not possible to optimise dosing systems for the control of odours in the liquid phase or to reliably predict the impact of dosing systems on the receiving wastewater treatment plants.

- **Gas Phase Technologies:** It is difficult to quantify and characterise odours from sewers without relying purely on costly, problematic and time consuming human olfactomatory systems. In addition, applications of odour abatement systems rely on empirical data with little fundamental understanding of the processes occurring for the removal of the odour.

Areas where the SCORe Project is achieving significant advances in knowledge leading to improved control of odour and corrosion in sewers are covered below.

NEW DEVELOPMENTS

**Prediction of Sulfide Generation in Sewers.**

Prediction of sulfide generated in sewers in the 1989 H2S Manual relied on empirical equations such as:

- Pomeroy’s Equation (Pomeroy, 1959)
- Boon and Lister’s Equation (Boon and Lister, 1975)
- Thistlethwaite’s Equation (Thistlethwaite, 1972)

These equations such as Pomeroy’s equation:

$$G = 0.0013 \times \text{BOD}_5 \times 1.07^{(T-20)}$$

continue to be used by water practitioners today (Dack, 2011; Shammay, 2010). This equation uses just two parameters, BOD5 and temperature for the prediction of the sulfide generation rate, G. While Boon and Lister equation uses COD rather than BOD5, and Thistlethwaite adds a third parameter, sulfate concentration.

There has been considerable research into the parameters affecting the sulfide generation rate (Hvitved-Jacobsen et al, 2002; Freudenthal et al, 2005) and these provide significant improvements over previous equations as more biological, chemical, and physical processes have been included. However, the kinetic expression for sulfide production still used an empirical approach limiting these models to steady-state conditions.

Improved understanding through the SCORe Project of physical, chemical and biological processes occurring within sewers has led to the development of an advanced mathematical model which is capable of predicting both spacial and temporal variations in sulfide concentration as well as other sewer parameters including GHG emissions (Sharma et al, 2011).

This sulfide generation model, the Sewex Model has been linked to sewer hydraulic models such as MOUSE to provide a dynamic model of sewer networks to predict the dynamic changes in sulphur compounds within the sewer system as a result of changing sewer characteristics such as diurnal variations (Wang et al, 2010).

**Bacterial Activity and the Rate of Corrosion**

It has been known for some time (Parker and Beer, 1965; MDWB, 1989) that the rate of corrosion depended on:

- sulfide concentration (H2S),
- temperature, and
- relative humidity (RH)

and that the corrosion of concrete sewers involved a succession of chemical and biological processes as the pH of the concrete surface is progressively lowered. Further it was understood that Thiobacillus Concretivorous (now known as Acidithiobacillus Thiooxidans) was responsible for the generation of sulphuric acid when the pH of the concrete surface dropped below pH 4 and that a RH of greater than 87% and a concrete moisture of greater than 4% was needed for the bacteria to be active. The highest rate of activity was understood to be at approximately 30 C.
The SCORe Project has used newly developed genomic analytical methods (Cayford, 2012) to identified the microbial communities present during corrosion of concrete sewers below pH 4. These studies have identified a far greater diversity of microbes which suggest that A. thiooxidans may not be the sole microbe responsible for corrosion of the sewers at low pH and that other process may also be involved. This research is continuing and promises to reveal a far greater fundamental understanding of corrosion processes at low pH.

Also a better understanding of concrete corrosion processes at neutral and high pH is being developed (Joseph, 2012). The role of carbon dioxide in the early corrosion processes has been found to be far less important than previously thought and that H2S concentration is the far more dominant factor in the early corrosion processes. Temperature and RH also influence the rate of corrosion at these neutral and high pH.

Concrete corrosion in sewers is being studied both in the field, with specially prepared coupons in six locations in Sydney, Melbourne and Perth and under controlled conditions in 36 corrosion cabinets in a laboratory (see Figure 3). In addition, historic records of corrosion and environmental conditions are being analysed with the objective to develop a new fundamental process based corrosion model to be able to accurately predict concrete corrosion rates in sewers under all conditions (Wells et al, 2011).

**Corrosion and Odour Control Methods**

The methods for controlling odour and corrosion in sewers has not changed significantly since the 1989 Manual, as shown in Figure 4 – Control of Odour and Corrosion in Sewer Systems which is reproduced from the 1989 Manual. Although the methods have not changed, the popularity of various chemicals used by the water industry in Australia to control odour and corrosion has seen some changes. A recent survey carried out by the SCORe Project (Ganigue et al, 2011) identified that there are five chemicals that are now popularly used by the Australian water industry:

- Magnesium Hydroxide,
- Sodium Hydroxide,
- Nitrate,
- Iron Salts, and
- Oxygen

Detailed laboratory and field testing has been conducted with these five chemicals (Gutierrez et al, 2008; Zhang et al, 2009; Jiang et al, 2009; Gutierrez et al, 2009; Pikaar et al, 2011) to gain a better understanding of the physical, chemical and biological processes involved with each chemical to enable:

- Optimal dosing rates,
- Appropriate dosing locations, and
- Mathematical modelling of the processes

Development of the Sewex model for predicting sulfide generation in sewers can now be used to do desktop evaluation of the performance of various chemicals with various dosing locations to optimise the control method selected (Sharma et al, 2008).

To further optimise the dosing of chemicals, on-line control strategies have been developed for the five popular chemicals using a level of sophistication of sensors appropriate to the application (Ganigue et al, 2012). Savings in chemical use of up to 50% have been achieved with the use of on-line control.

In addition to optimising the use of the popular chemicals for control of odour and corrosion, the SCORe Project has developed two new methods:

- Free Nitric Acid (FNA), and
- In-sewer electrochemical generation of chemicals for control of sulfide.

FNA has a strong biocidal effect on the biofilm in sewer pipes that generate the sulfide (Jiang et al, 2011). This control method is very cost effective as the FNA can be dosed intermittently as the biocidal effect has been found to reduced sulfide generation by more than 50% for up to 14 days.

An exciting new method for control of odours in sewers is by generation of chemicals such as sodium hydroxide and oxygen within the sewer by electrochemical process to control the generation of sulfide (Pikaar et al, 2012). This method has enormous potential as the overall cost is much less than traditional chemical dosing methods and avoids the transport and storage of large amounts of hazardous chemicals.

A laboratory method used in the SCORe Project, called the SCORe-CT method (Gutierrez et al, 2011) can now be used to evaluate prospective odour control additives for sewer. This allows new odour control additives (chemicals or biological agents) to be evaluated under controlled laboratory conditions where one wastewater line has the additive dosed and the other wastewater line is used as a control. This removes the natural variations that occur in the field that make evaluation of additives open to interpretation.

**Ventilation of Sewers**

The objectives of ventilation systems in sewers, as stated in the 1989 H2S Manual are:

- Maintain zero relative velocity between wastewater and ventilating air to minimise the rate of H2S emission and evaporation from the wastewater surface, &/or
- Change the air sufficiently to maintain dry sewer structures at all times, (i.e. never allow the air dew point to exceed wall...
Achieving these objectives with natural ventilated systems has always proven very difficult to predict. The natural forces influencing ventilation are a fine balance between:

- Relative density between sewer air and outside air,
- Wastewater flow induced drag,
- Changes in barometric pressures along a sewer, and
- Wind velocities over ventilation stacks.

There have been several empirical algorithms proposed for predicting natural ventilation air movements, the most popular being the Pescod & Price Equation (Pescod and Price, 1982), but these have not been widely used for the ventilation of sewers as the results have been unreliable. Design of natural ventilation systems have generally been designed on practical measures such as alternating short induct vents followed by tall educt vents. However these systems have often failed to protect nearby residents from escaping odours and in many cases the vents have been either closed and forced ventilation systems installed.

In conjunction with Water Environment Research Foundation (WERF) in the USA, the SCORe Project has developed a new algorithm based on the conservation of momentum (Ward et al, 2010; Hamer et al, 2012)) which has proven in field testing in Adelaide and Perth to be much more reliable than previous models. A spreadsheet based tool has been developed based on the conservation of momentum algorithm which can be used to predict both natural and forced ventilation air movements in sewers. This SCORe Ventilation Tool is now being used by many of the water utilities involved in the project.

The new ventilation algorithm is also being used in a supplementary component of the Sewex Model to provide a virtual dynamic (time stepped) prediction of air movements and gas phase H₂S concentrations within a sewer network.

**Deodourisation of Foul Air**

The odourous substances in sewer air have long been known to consist of a wide range of compounds which can be classified as either inorganic gasses or organic vapours. The odourous inorganic gases common in wastewater which arise from biological activity are H₂S and ammonia. While the principal odours of an organic nature arise from anaerobic decomposition of compounds containing nitrogen and/or sulphur. These include mercaptants, indoles, skatoles and other organic nitrogen and/or sulphur compounds.

A comprehensive odour sampling and analysis campaign is being undertaken in Sydney and Melbourne to get a better understanding of the chemical and biological transformations that occur in sewers and where various odourous compounds may be expected within a sewer system.

In conjunction with the field testing campaign, various popular odour abatement systems within the sewer system are also being monitored to determine their effectiveness in removing various odourous compounds.

Standard sampling and analysis techniques are being developed to provide consistent odour analysis results across Australia. A survey conducted by the project (Sivret et al, 2010) revealed that there is currently a wide ranges of practices employed by different water utilities in Australia.

**Rehabilitation of Sewer Pipeline**

Methods for rehabilitating sewers that have been compromised by corrosion have developed rapidly since the 1989 H₂S Manual was prepared (US-EPA, 2010). Many of these systems are proprietary relining systems with each system requiring individual assessment for each particular application depending on such things as ease of access, control of wastewater flow, etc, as much as the lining materials corrosion resistance. Rapid development has also been made in coating systems which are applied to the internal surface of concrete sewer pipes and/or manholes to protect them from further corrosion and extend their useful life.

Extensive laboratory and field testing has been conducted as part of the SCORe Project on the following popular coating systems:

- Epoxy resin coatings
- Sacrificial coating – Calcium Aluminate Cement (CAC), Gunite and Calcareous Aggregate Concrete

The field testing has included installation of coated coupons in Sydney, Melbourne and Perth (see Figure.3) as well as many in-situ cores of coatings applied up to 15 years ago.

Considerable variation has been identified in the performance of each brand of epoxy resins in terms of resistance to acid permeation and effective life expectancy (Valix et al, 2011). Further studies are being conducted on these epoxy resins to identify performance and causes of delamination of these products.

Similarly the effective life expectancy of various sacrificial coatings have been determined and parameters affecting this performance identified.
Predictive models to determine effective life expectancy of various coating systems are being developed as part of this project which will allow industry to optimise their use of these coating systems.

CONCLUSION

Halfway into its five year lifetime, the SCORe Project has achieved many milestones and has been able to provide to Industry Partners many valuable deliverables, some of which have already caused major changes to industry practices and decision making.

By developing a greater fundamental understanding of the processes involved in various aspects of odour and corrosion, the water industry will be able to move from a reactive approach to the control of odour and corrosion to one of being pro-active and take control of odours and corrosion in sewers.

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(for more details see: www.score.org.au).

REFERENCES


Figure 1 - An overview of the SCORe Project

Figure 2 – The Sulfide Corrosion and Odour Problem (from 1989 H₂S Manual)
Figure 3 - Laboratory Corrosion Chambers (a) and Field Corrosion Coupon Installations (b), (c) and (d)

Figure 4 - Control of Odour and Corrosion in Sewerage Systems (from 1989 H₂S Manual)