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New Insights into Sewer Odour and Corrosion

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ABSTRACT

Until recently, little progress had been made since the 1970's in the development of a fundamental understanding of odour and corrosion in sewers. Empirical methods such as Pomeroy's equations are still predominantly used by industry to predict sulfide levels. A major initiative in Australia, the Sewer Corrosion & Odour Research (SCORe) Project, which is being funded by most of the major water utilities as well as the Australian Research Council, is closing many of the knowledge gaps and providing knowledge and technology support to the Australian water industry for cost-effective and efficient management of corrosion and odour in sewers. The research project is using laboratory studies to identify fundamental understandings, field studies to confirm and calibrate these new understandings, and then developing mathematical models to support and optimise the application of this knowledge by industry.

Keywords: odour; corrosion; sulfide

INTRODUCTION

With a growing world population and increased urbanisation, modern sewers started to be constructed around 150 years ago. There is now an enormous investment in sewers but this investment is being severely compromised by odour and corrosion problems.

Initially sewer design was purely a matter of hydraulics with civil and structural considerations. Modelling of H_2S generation in sewer started in 1940s (Pomeroy and Bowlus, 1946), but good progress was not made until the 1970s. In one of the earliest models presented, Pomeroy and Bowlus (1946) proposed that the amount of sulfide produced in a sewer biofilm is proportional to its surface area and the effective biochemical oxygen demand (BOD). Thistlethwayte (1971) amended the model by including the effects of velocity and sulfate concentration.

A common problem with all these models is that only a few factors among many others affecting H_2S production are considered, resulting in case-specific values. In addition, due to other factors affecting sulfide production such as presence of oxygen, large variations of the rate constants used in the model makes the predictions unreliable (USEPA, 1974; Hydrogen Sulfide Control Manual, 1989).

Despite these limitations, this is still the common approach used by industry to predict sulfide levels for odour and corrosion control.

Liquid phase control of corrosion and odour producing compounds is being widely used by industry. This involves the addition of chemicals to wastewater to reduce the production of compounds of concern (particularly H_2S) or to reduce their emission from the liquid to the gas phases (USEPA, 1974; Boon and Lister, 1975; Hydrogen Sulfide Control Manual, 1989). The approach is highly empirical due to the lack of fundamental understanding, leading to inefficiencies and poor performance in many cases.

In recent years there have been significant developments in analytical methods (Keller-Lehmann et al, 2006; Monteny et al, 2000) and equipment (Gostelow et al, 2003; Sutherland-Stacy et al, 2008), microbiological assessment (Hvitved-Jacobsen, 2002; Mohanakrishnan, 2008), laboratory techniques (Gutierez, 2006) and computer modelling (Hvitved-Jacobsen et al, 1998; Sharma et al, 2008) . Advanced mathematical models, which are capable of predicting both the spatial and temporal variations of sulfide and several other key wastewater parameters have been developed and demonstrated (Freudenthal et al., 2005; Sharma et al., 2008). Such advanced models have started being taken up by industry to replace the Pomeroy's equation or its variants proposed in the 1970's, but the latter models are still being dominantly used by industry for the prediction of sulfide production in sewers.

Optimal corrosion and odour management has clearly 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.

NEW DRIVERS

The generation of hydrogen sulfide (H_2S) has long been known to be a major cause of corrosion and odour problems in sewer systems (Latham, 1873; Pomeroy, 1946). When anaerobic conditions prevail in a sewer system, sulfate present in the wastewater is reduced to sulfide by sulfate-reducing bacteria (SRB) residing in biofilms on the walls of the pipelines. This results in emission of H_2S to the sewer atmosphere, causing odour and corrosion problems in partially-full pipe sections, manholes, vent pipes and other places in contact with air. Rising mains which operate with a full pipe consume oxygen and become anaerobic, contributing considerably to H_2S production in a sewer system.

In Australia, the problem is generally exacerbated by the hot climate as well as relatively flat coastal terrain with low population densities, resulting in long rising mains that collect sewage from catchments with sandy soils and where a high potential often exists for intrusion of sulfate-rich seawater.

There has been heightened interest in the management of odour and corrosion in sewers in recent years for a number of reasons:

1. The sewer systems are being extended to fringe populations around the major cities (Shammay, 2010) with ever increase size of the collection systems and greater dependency on the pumping of sewage and hence greater generation of sulfides in the system.

2. Water restrictions and demand management of water supplies is resulting in significantly lower flows and higher concentrations of COD, sulfates and other pollutants (McDonald, 2010). This then produces longer detention times in rising mains and the quicker onset of anaerobic conditions which cause generation of more H_2S and to potentially higher concentrations (due to higher sulfate concentration).

3. Warmer climates over the last decade (IPCC, 2008) which reduces the DO concentration, encourages the more rapid depletion of the oxygen in the sewer and stimulates the generation of H_2S by the sulfate reducing bacteria (SRB).

4. Trade Waste regulations have reduced the amount of heavy metals (and other pollutants) that are discharged to sewers which has reduced the precipitation of the heavy metal sulfides in the sewers. Precipitation of the heavy metal sulfide would reduce the H_2S concentration in the sewage. In addition it is believed that the heavy metals also had a inhibitory effect on the SRB which slowed the generation of H_2S in the sewage.

There do not appear to be any off-setting system changes to reduce the odour and corrosion problems that from inferred evidence are becoming more severe. In fact there is a suggestion that odour complaints are increasing due to a lowered tolerance to odours by the general public (personal observation) which exacerbates the problem further.

PROJECT STRUCTURE

A major step forward to fill the above gaps is being taken in Australia with a new initiative called the Sewer Corrosion & Odour Research (SCORe) Project which aims to provide knowledge and technology support to the Australian water industry for cost-effective and efficient management of corrosion and odour in sewers.

The size of this problem is reflected in the broad support being provided to the Project by water utilities throughout Australia. There are eleven (11) industry partners representing approximately 60% of Australia's population and five (5) research partners. The Project started in late 2008 and will run for 5 years with a total budget of around $20 million.

The SCORe Project has ten (10) separate research teams or subprojects (SP) which are located in various research centres around Australia and are grouped into four (4) themes or areas of interest; corrosion processes, gas phase technologies, liquid phase technologies and knowledge management systems. This research is being peer reviewed by international experts and shared internationally through strategic collaboration agreements.
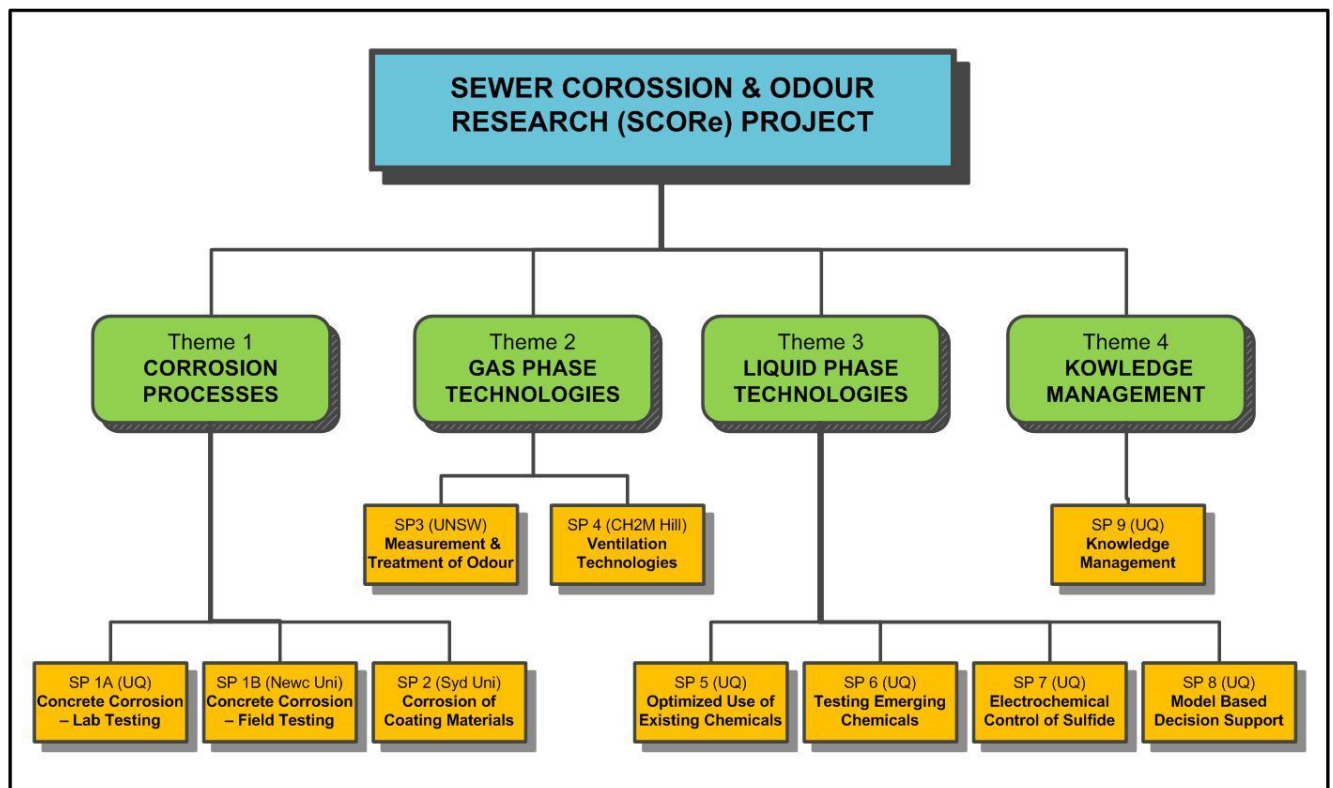

**Figure 1 – SCORe Project Structure**

This project brings together the scientific knowledge of world-leading researchers and the vast amount of practical expertise available in the Australian water utilities, which will ensure practical outcomes based on fundamental scientific knowledge. The skills and expertise possessed by the research providers and industry partners are very diverse yet complementary, enabling the integration of process engineering, mathematical

modelling, environmental chemistry, material science and microbiology, together with operational experience, in the search for solutions.

METHODOLOGY

This initiative has adopted an approach which integrates:

    1) Laboratory based research to identify key fundamental scientific processes to close knowledge gaps,
    2) Field studies applying the new scientific knowledge to confirm and calibrate the new knowledge, and
    3) Mathematical modelling to support and optimise the application of this knowledge by industry and to direct further laboratory research.
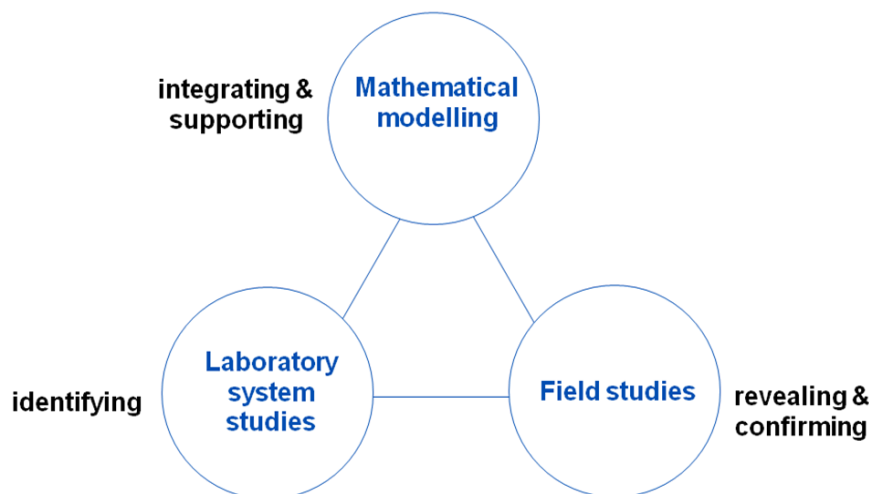
Figure 2 – Methodology of the SCORe Project

The aim of the SCORe Project is to review state-of-the-art knowledge and practice based on both published (USEPA, 1991) and grey literature, and to identify key knowledge gaps (WERF, 2003; WERF, 2007) and to develop new knowledge and understanding as well as improve and optimise technologies for the control of odour and corrosion.

KNOWLEDGE GAPS

Common methods currently used for the control of odour and corrosion are shown in **Figure 3**. However the details of these processes have not been the subject of substantial scientific research for several decades, but rather development of odour and corrosion knowledge has been left mainly to the practitioners who have applied this knowledge to their specific sewer systems where odour and/or corrosion problems occurred.

H_2S is generated by sulfate reducing bacteria (SRB) that grow in slime layers (biofilms) on the internal wetted perimeter of sewer walls under anaerobic conditions. SRB grow along with other micro-organisms such as fermenters and methane formers in anaerobic environments where organic compounds are plentiful and together produce compounds causing odour and corrosion as well as health and safety hazards (lethal at 300ppm in air).

It is seldom feasible to completely prevent the bacterial biofilm activity that leads to problems in sewers. Control strategies usually focus on H_2S as it is the major primary odorous product of the biofilm. H_2S is a highly odorous (and poisonous) gas that can be readily detected and exists in aqueous equilibrium as dissolved (or particulate) sulfide ions. The common control strategies for H_2S involve dosing chemicals that either oxidise it to less problematic forms (e.g. sulfate) or "lock" it into forms that are not volatile (i.e. HS^-/ S^{2-} ions that

dominate the equilibrium at alkaline pH, or metal precipitates such as iron sulfide). $H_2S_{(aq)}$ has very low solubility in water and will volatise into the headspace above the wastewater, particularly under turbulent conditions. H_2S in the headspace may be oxidised to sulfuric acid by bacteria which grows on surfaces under moist aerobic conditions. This sulfuric acid can cause corrosion of concrete, mortar or metal sewer infrastructure. Steel and alloys of copper are readily corroded to flakes of metal sulfide.
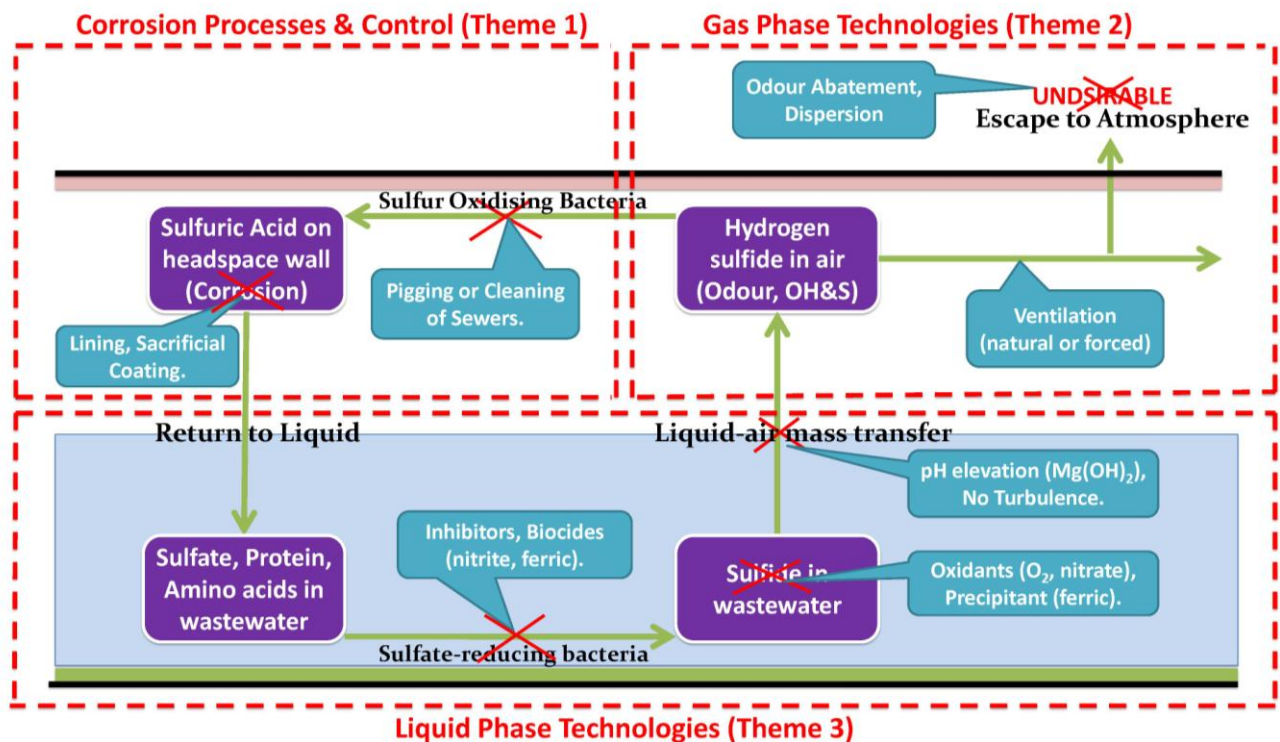

Figure 3 – Odour & Corrosion Processes and Control Methods in a Sewer

Some of the basic knowledge gaps that still exist include:

1. Corrosion Processes and Control:
   - The rate of corrosion of concrete pipes for various H_2S concentration and how this varies over time.
   - How environmental factors such as temperature and humidity affect the rate of corrosion.
   - How fluctuations in H_2S concentration and environmental factors, both diurnal and seasonal affect the rate of corrosion.
   - How the microbial population and production rate of H_2SO_4 and other corrosive products change over time.
   - How the mineralogy, permeability and strength of concrete pipe and the corrosion layer change throughout the different stages of the corrosion process.
   - The spatial variability of such changes around the sewer circumference.
   - Chemical, physical and microbiological stability requirements for coatings to protect concrete pipes from microbial activity and acid corrosion.

The combination of all these knowledge gaps regarding corrosion processes leaves the estimation of the corrosion rate and life expectancy of pipes a very uncertain measure and is almost entirely based on empirical data about the past performance of the pipes under similar conditions.

2. Gas Phase Technologies:
   - There exists little way to correlate the chemical composition of a gas with its odour intensity and character.
   - Little knowledge about the composition of the main odourants in the gas coming from sewers and how this composition varies through the sewerage system.
   - The chemical and biochemical transformation processes of odourous gases that occur in sewers.
   - Reliability of sampling, transport and storage procedures for analysis of sewer gases.
   - Methods for predicting the effective life expectancy of adsorption odour abatement technologies in any particular application or the time left before odour breakthrough.
   - Effectiveness of biological odour abatement systems for removal of odourants other than H_2S.
   - Ability to quantify the impact of environmental factors such as temperature and humidity on the performance of odour abatement technologies.
   - Prediction of air movement in sewer headspace under both natural and forced ventilation conditions to identify H_2S concentrations in sewer networks.

The combination of these knowledge gaps mean that it is difficult to quantify and characterise odours from sewers without relying purely on human olfactomatory systems and that the application of odour abatement systems rely on empirical data from similar applications.

3. Liquid Phase Technologies:
   - The composition and spatial variation of the various microbiology in the biofilm on the wetted perimeter of a sewer and how these function and interact in the production of H_2S and other odourous compounds.
   - A complete 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 due to industrial discharges, etc.
   - The impact of chemicals commonly used to control H_2S in sewers such as O_2, NO_3, $Mg(OH)_2$, Fe_2Cl_3, etc on the biofilm and other chemical and biochemical side reactions that may occur.
   - An understanding of the processes which emerging biomaterials claim to use to control odours in sewers.

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.

RESULTS TO DATE

Despite being operational for just under 2 years the project has been able to deliver to industry many outcomes. Some of these outcomes are listed below:

Analytical tools and protocols-
- Laboratory corrosion chambers for testing corrosion of concrete coupons under controlled conditions have been developed and are in operation with the first set of coupons recovered for analysis;
- Concrete coupons have been installed in sewers in Sydney, Melbourne and Perth to monitor corrosion. The first sets of coupons have been recovered from Sydney and Melbourne;
- Concrete coupons with coatings have been prepared and installed with the concrete coupons both in the laboratory corrosion chambers and the field sites at Sydney, Melbourne and Perth.

- Standard protocols for the physical, chemical and biological analysis for the corrosion assessment of concrete and coatings have been established using biological and physical samples from sewers.
- A photogrammetric method for measurement of surface depth lost due to corrosion has been developed for laboratory measurement and is being further developed for field measurement.
- A laboratory based reactor system, SCORe-CT has been developed that replicates the behaviour of a sewer rising main with two parallel lines; a experimental line to which odour control materials can be added, and a control line to use as a baseline comparison without the odour control material added.
- An activated carbon (AC) test rig has been developed to determine the performance of any particular AC material with regards to its adsorptive rate for various odorous gases (% removal) and its adsorbtive capacity (expected life).

Decision support and knowledge management-
- Industry survey conducted and a report prepared on the methods used by Australian industry for monitoring and analysis of sewer odourants with recommendations for improvements.
- Industry survey conducted and a report prepared on the odour abatement technologies used by Australian industry for control of sewer odours with recommendations for further research.
- Developed a new ventilation model and conducted field testing in Adelaide and Perth to verify the model.
- Industry survey conducted on the chemical dosing systems used by industry to control odour and this information used to select chemicals to be studied further in this Project to optimise their performance;
- A literature review conducted of new and emerging biochemical products that are available for odour control in sewers and a report prepared with recommendations of products to be tested under laboratory conditions. Testing of 2 of these products has been complete;
- The SeweX model has been enhanced to better reflect carbon transformations and the effect of trade wastes and flow velocity on sulfide generation;
- A web-based knowledge management system has been developed to make knowledge generated in SP1-SP8 readily available to Industry Partners.

New technology-
- Proof of concept for electrochemical control of sulfide in sewers has been demonstrated first with synthetic wastewater and then real wastewater. Design of a laboratory scale field pilot plant has been completed and arrangements for a trial installation at the Gold Coast has commenced;
- Training to Industry Partners on the use of the SeweX model has been delivered. Some Industry Partners have now linked the SeweX sulfide model to their hydraulic network model to predict potential 'hot spots' for odours in their sewer networks;
- The inhibitory effect of both ferric chloride and nitrite on the generation of both sulfide and methane has been identified. This may significantly reduce the amount of chemical required to be dosed to control sulfide and methane to acceptable levels. Trial applications are planned for Sydney, Melbourne and Adelaide.

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