Report by UWI doctoral researcher Micaela Pacheco Fernández (S1)

Project number: S1

First and last name of doctoral researcher: **Micaela Pacheco Fernández**

(Working) title of doctoral project: **Interfaces in sewer systems - corrosion and odour**

Name of supervisors: Prof. Dr. rer. nat. Dietmar Stephan (TUB), Prof. Dr.-Ing. Matthias Barjenbruch (TUB), Prof. Prof. Dr. rer. nat. Ulrich Szewzyk (TUB), Dipl.-Ing. Regina Gnirss (BWB)

2. Description of doctoral project and research results achieved to date:

State of the art

Some of the main problems associated to sewer networks are odour nuisances and corrosion. At the present time, these conditions commonly arise due aging of the sewer network (old systems), weather variations (dry and wet periods) and the reduction of the water consumption in cities due to the environmental consciousness of their inhabitants. Moreover, in Berlin the problem is aggravated by the high sulphate concentrations in drinking water. Altogether, these events lead to high retention times of wastewater in sewer pipes. The higher the retention time, the more oxygen is consumed, leading to anaerobic conditions. Therefore, hydrogen sulphide (H_2S) is produced in the wastewater due to biological processes and then further released into the sewer atmosphere, producing the unpleasant smell of rotten eggs (see fig. 1). In addition, H_2S generation represents a high risk to human health, specially to sewer workers, causing irritation and nausea at a concentration above 10 ppm as well as respiratory and eye injuries above 50 ppm. Moreover, concentrations above 700 ppm are known to be lethal (Park et al. 2014).

Furthermore, H_2S can lead to structural failure of the sewer pipe system. It has been identified that a total sulphide concentration within the range of 0.1-0.5 ppm can cause minor concrete corrosion while major concrete corrosion can be observed at concentrations higher than 2.0 ppm (Park et al. 2014). This leads to high costs for sewer maintenance: In Germany, yearly costs due to sewer corrosion rise to over $ 50 billion (Wells et al. 2009).

In the future, these problems are expected to be further aggravated through climate and demographic change. Therefore, research institutions need to respond to the expected changes. In order to solve the problems arising from sulphurous compounds in sewer networks, several approaches have been studied.

One of the strategies consists on evaluating and identifying the wastewater and hydraulic parameters that enhance formation of H_2S such as: pH, temperature, DOC (dissolved organic carbon), turbulence, area/volume ratio etc. Another strategy is to apply mitigation strategies in the sewer networks to control H_2S. Commonly used methods are based on chemical or biological treatments.

Depending on their action mechanism, chemical strategies may be divided into three main groups: oxidising agents (e.g. oxygen), pH regulators (e.g. sodium hydroxide) and precipitant agents (e.g. iron salts). In addition to the commonly used techniques, bacteria inhibitors are also being studied. Analogously, biological methods may be divided into microorganisms and enzymes. When neither of the mentioned strategies is possible, treatment of the foul air may be provided by exhaust air treatment strategies. These can be divided into three main groups depending on their action principle: physical, biological and chemical.

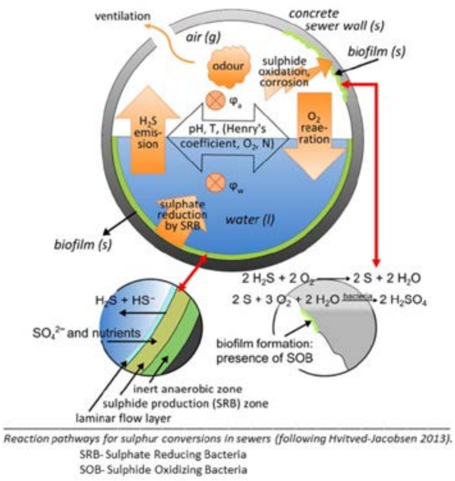

Figure 1: Overview of the formation process of hydrogen sulphide in sewer systems (UWI 2018)

Motivation and research idea

The use of the research sewer pilot plant of the *Berliner Wasserbetrieben (BWB)* enables the study of hydraulic conditions, mitigation strategies and exhaust air treatment methods under controlled conditions. One of the main motivations for this research is precisely the opportunity of using a large scale model and not only lab scale systems is one of the main motivations for this research. The pilot plant is equipped with a water measurement system, which allows online measurements of pH, redox potential, temperature and O_2-concentration. Furthermore, the system includes a UV-VIS device for COD (chemical oxidation demand) and TS (total solids) measurements. A gas measurement system is also installed at the facility enabling oxygen and hydrogen sulphide measurements.

Taking advantage of the use of the sewer pilot plant, the idea of the following research is to understand the hydraulic processes that influencing the formation and the mass transfer of H_2S from the aqueous phase into the gas phase.

Special attention will be paid at this point to the role of turbulence. This hydraulic parameter is of special interest: high turbulences enhances H_2S mass transfer from the aqueous phase into the gas phase and the impact of H_2S being only effective after released into the gaseous phase.

Later, turbulence should be enhanced by installing obstacles and/or hydraulic jumps in the gravity pipe in order to release higher concentrations of H_2S into the sewer atmosphere so that exhaust air treatment measures can be studied and compared. One of the challenges that also need to be addressed before installing obstacles or hydraulic jumps is how to avoid deposition of transported slur material.

Finally, mitigation strategies for H_2S control will be studied. The main focus will rely on biofilm inhibitors, since one of the main sources for H_2S formation in wastewater is the biological reduction from sulphate (SO_4^{2-}) to sulphide (S^{2-}).

Other strategies under consideration, are biological ones, such as specially adapted cultures of microorganisms. These strategies should be taken into account as an opportunity for the development of more environmental friendly strategies. However, the improvement and adaptation of commonly used mitigation strategies (e.g. the combination of several chemical strategies) will be also addressed in order to establish more effective-cost solutions.

Moreover, a collaboration with project S2 is planned, whose aim of the collaboration is the development of a model for the sewer pilot plant. The model should help in predicting the behaviour of the pilot plant before studying strategies for H_2S control, so that the time planned for the trial and error periods can be reduced.

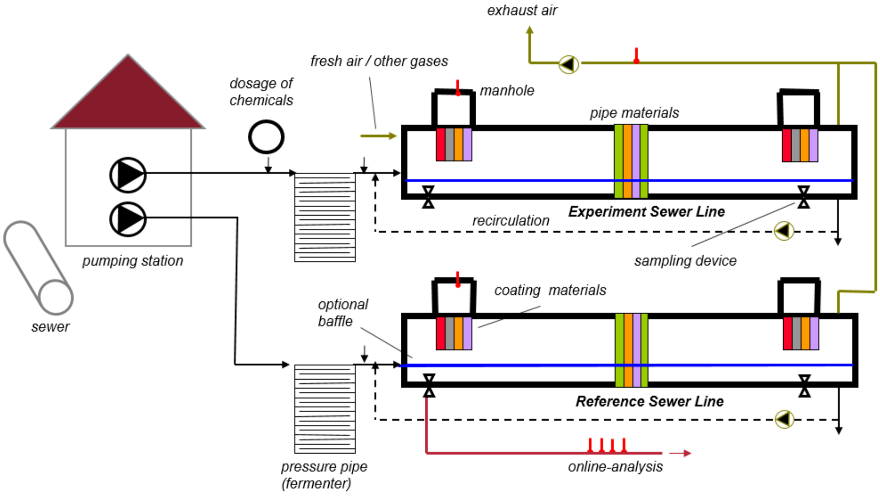

Figure 2: Schematic layout of the research sewer pilot plant (Barjenbruch et al. 2009)

Scientific project relevance

This project addresses the study of control strategies for odour and corrosion in a large scale system (pilot plant) under controlled conditions. The use of the pilot plant specifically allows biofilm investigations as well as the monitoring of wastewater and air parameters. In addition, the system allows the comparison between the matter of study and the reference system. Last, results of the project will also allows the comparison of several strategies for H_2S development and control, before their implementation in real sewer systems.

Research demands

To further clarify the scope of the project, the following scientific questions should be answered during this project:

1) How does turbulence affect the mass transfer of hydrogen sulphide from the aqueous phase into the air phase?
2) Which exhaust air treatment strategies are more effective for degradation of odorous compounds?
3) Which mitigation strategies achieves best results for hydrogen sulphide control?
4) Are there more environmental friendly mitigation strategies than those currently used?
5) How is the price-performance relationship of the exhaust air treatment measures and mitigation strategies?

Objectives

The main objective of the project is to fully understand the processes and parameters involved in the formation and mass transfer of H_2S, stressing the role of turbulence. Moreover, another priority is the study of physical, chemical and/or biological measures for exhaust air treatment. Last, this work will deal with the development of strategies for the inhibition and elimination of hydrogen sulphide. In this case, the focus emphasises research on more environmental friendly and a lower cost mitigation strategy.

Work programme incl. proposed research methods

WP 0 ***'Preparation, knowledge acquirement, course attendance´***

The aim of this work package is to acquire basic knowledge on the topic. This includes a broad literature research, attendance of the mandatory UWI core courses and taking some of the elective courses. The literature research is more focused on the specific knowledge of sewers system and their interaction with sulphurous compounds. Attending the mandatory courses provides an overview on urban water interfaces as well as further knowledge on other UWI projects. The elective courses are planned as a further training within the programme. In this case the courses may address general skills such as scientific writing or filling specific knowledge gaps. The time spent on this exposé and on the UWI Summer School is also included in this work, since a large amount of literature sources were reviewed with this aim.

Moreover, another step included in this project is learning the operation of the sewer pilot plant. For this purpose I will be joining my predecessor Daneish Despot (UWI kollegiate from the first cohort) at the pilot plant until the end of the year. After this time, I should be able to take over the sewer pilot plant and operate it on my own.

WP 1 ***'Influence of turbulence on mass transfer processes regarding hydrogen sulphide formation'***

The first work package studies the influence of turbulence on mass transfer processes regarding the hydrogen sulphide formation. These factors are very important for hydrogen sulphide control, since H_2S is formed in the aqueous phase, but its impact is only effective after transfer into the gas phase (Carrera et al. 2017). This topic focuses on the hydraulic and mass transfer processes that take place in the gravity pipe, were both the aqueous and the gas phase, are present. Therefore, this WP is based on the water-air interphase in sewers.

Turbulence is a hydraulic condition that can be of advantage in aerobic wastewaters, since it enhances the oxygen exchange between the gas and the aqueous phase. However, in anaerobic waters, turbulence enhances the release of hydrogen sulphide and other odorous gases into the air. On these grounds, the influence of turbulence on mass transfer processes between both phases is the main point of focus. For this aim, the current hydraulic conditions (without turbulence) in the gravity pipe will be studied. Later on, the influence of turbulence on mass transfer processes will be investigated. This includes the consideration of models and equations for turbulence (e.g. Reynolds-Averaged Navier-Stokes equations) as well as gas exchange equations (e.g. Henry´s Law). Following up on this idea, the influence of temperature on turbulence process will also be addressed. Based on this idea a cooperation with project S2 is planned in order to create a model that describes the turbulence in the gravity pipe of the sewer pilot plant.

Last, after having understood the influence of turbulence on mass transfer processes, the main goal is to enhance the transport of hydrogen sulphide from the aqueous phase into the gas phase. This enables the investigation of exhaust air treatment strategies, which will be studied and described in WP 2. To achieve this goal, obstacles and/or hydraulic jumps will be placed in gravity pipe to enhance turbulence and therefore hydrogen sulphide mass transfer.

WP 2 ***'Exhaust air treatment'***

In sewer networks where the prevention of hydrogen sulphide through proper hydraulic conditions or chemical dosing is not possible or cost effective, hydrogen sulphide is released into the sewer atmosphere and vented within the sewer system or at sewer pump stations (Shammay et al. 2016). This causes unpleasant smelling odours (smell of rotten eggs) and may also represent a risk to human health. In these cases exhaust air treatment of the foul air is required. Based on these grounds and following up on WP 1 the aim of this WP is to study the effectiveness of several exhaust air treatment methods. A collaboration with the water-air flow model developed in the project T3 (first cohort) and extended in S2 (second cohort) is planned.

The exhaust air treatment measures may be based on physical, chemical and/or biological action principles. One of the main goals is the evaluation of their reduction potential regarding the elimination of hydrogen sulphide and methane. Moreover, the study will include an evaluation of their effectiveness and their costs (price performance relationship). In order to carry out this evaluation a collaboration with an exhaust air treatment company should be established. One of the strategies planned to be evaluated is a method based on activated oxygen and its oxidation potential to neutralise odorous substances (Hippgen Luftreinigung 2018). Other strategies being considered are biofilters or adsorption methods. Biofilters are used to degrade odorous contaminants by microorganisms in a carrier surface. Adsorption methods are commonly operated with activated carbon as an adsorbent. In this case, odorous substances are removed through adsorption onto the activated carbon (Weismann & Lohse 2007, Schammay et al. 2016). This WP is closely related to the first one and can be carried out simultaneously as soon as high turbulence rates are obtained in the gravity pipe.

WP 3 ***'Mitigation strategies'***

The third work package of the doctoral thesis focuses on the biofilm-wastewater interface. It deals with mitigation strategies for hydrogen sulphide control, in order to prevent odour and corrosion in the sewer system. These strategies are of special interest, since some of them may address the problem before it arises. Some of the strategies being considered are biofilm inhibitors as they suppress biofilm growth and therefore avoid the biological reduction of sulphate to sulphide. Other strategies taken into account are biological methods (e.g. specialised bacteria) as they might be a key parameter for developing more environmental friendly strategies. Last, combinations of chemical methods will also be studied in this work package (e.g. the magnesium hydroxide $Mg(OH_2)$ and ferric chloride ($FeCl_3$)). However, during the doctoral research other ideas may also arise.

As an example, the use of the pH regulator ($Mg(OH)_2$ is of special interest for controlling H_2S emissions. This substance is commonly used in other countries such as Australia, but its application has not been specifically studied in Germany. Therefore, one aim of this WP is to study the effectiveness of this product in German wastewaters and also its combination with a precipitant agent. Furthermore, all products will be investigated regarding their price-performance relationship as well as their impact on the environment. Last, all products will be also evaluated for methane control.

Collaboration

Close collaboration is planned with Daneish Despot (UWI kollegiate from the first cohort) as we will be both working on the sewer pilot plant. Furthermore, cooperation is also aimed with Katharina Teuber (first cohort student, project T3) and Abhinav Dixit (project S2), since both of them are working on the modelling of sewer processes. In this case, the experiments at the pilot plant will provide data for the modelling stages. Last, a collaboration is planned with Niranjan Mukherjee (project H4), in order to study the properties of the biofi lm present in the sewer pilot plant.

References

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3. Comments on the qualification programme and supervision strategy:

Participation in the following Research Training Group events:

1. Core courses
   - Urban interface processes – fluxes, transport, interactions (3 ECTS)
   - Urban freshwater ecology (3 ECTS)
   - Modelling and measuring concepts of interface processes (3 ECTS)
2. Elective courses
   - Einführung in mathematische und statistische Methoden der Umweltforschung (6 ECTS)
   - English for Academic Purposes - Academic Writing Skills and Oral Presentation Skills C1 (6 ECTS)
   - Kolloquium Wasserwesen (3 ECTS)

Research stays or internships at other research institutions both at home and abroad:

In order to promote academic exchange and to gather further knowledge on the topic, two internships are currently being considered. The first option is a stay at the University of Queensland (Australia) in the Advanced Water Management Center. The second option is an internship at the University of Aalborg (Denmark) in the urban water research group.