Initial steps towards a framework to systematically deal with sulfide-induced corrosion problems in sewers

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Abstract

Many of the problems occurring in wastewater collection systems are directly or indirectly caused by hydrogen sulfide. Hydrogen sulfide is formed under anaerobic conditions, and such conditions may occur at several locations in the sewer infrastructure. Information from the many scientific papers on this subject are illustrated with examples from the sewer infrastructures managed by Aquafin (Flanders, Belgium). In addition, lessons drawn from a case study are discussed, which may be taken into account in developing a framework to systematically and efficiently deal with corrosion problems in practice.

Keywords

hydrogen sulfide, biogenic sulfuric acid corrosion, sewer infrastructure

INTRODUCTION

Aquafin was established in 1990 by the Flemish government and is responsible for the design, construction, operation and pre-financing of the supra-municipal wastewater treatment infrastructure of Flanders (Belgium), and serves approximately six million PE (Population Equivalent). Cities and municipalities are responsible for their local sewer systems, whereas their sewers connect to Aquafin's collector (or interceptor) sewers and force mains transporting the wastewater to the appropriate wastewater treatment plant.

At the end of 2008, Aquafin's assets included 228 wastewater treatment plants, 958 pumping stations and approximately 4500 km of collector sewers. The wastewater collection system, which covers the majority of Aquafin's assets is the main focus of this paper. More precisely, this paper deals with the problems Aquafin and other wastewater service providers around the world are facing today, that can be attributed to the presence of hydrogen sulfide in the sewer system.

To introduce the terminology used in this paper, the different parts of a conventional wastewater collection system are shown schematically in Figure 1. Wastewater from the households is mainly and preferably transported through gravity sewers, but it is often not possible to reach the wastewater treatment plant in this manner. Therefore, pumping stations are required, where the wastewater is collected in a wet well or pump sump equipped with level measurement instruments monitoring the amount of wastewater present. When a certain water level is reached in the sump, the wastewater is pumped to a higher level through a force main (or pressure main or rising main) and discharged in an inspection chamber or manhole from which the wastewater continues its path through gravity sewers. This is typically repeated until eventually the wastewater arrives at the wastewater treatment plant. Needless to say that the sewer system is hardly ever a linear system, and often many sewer pipes are connected with each other to form a complex network with many branches.

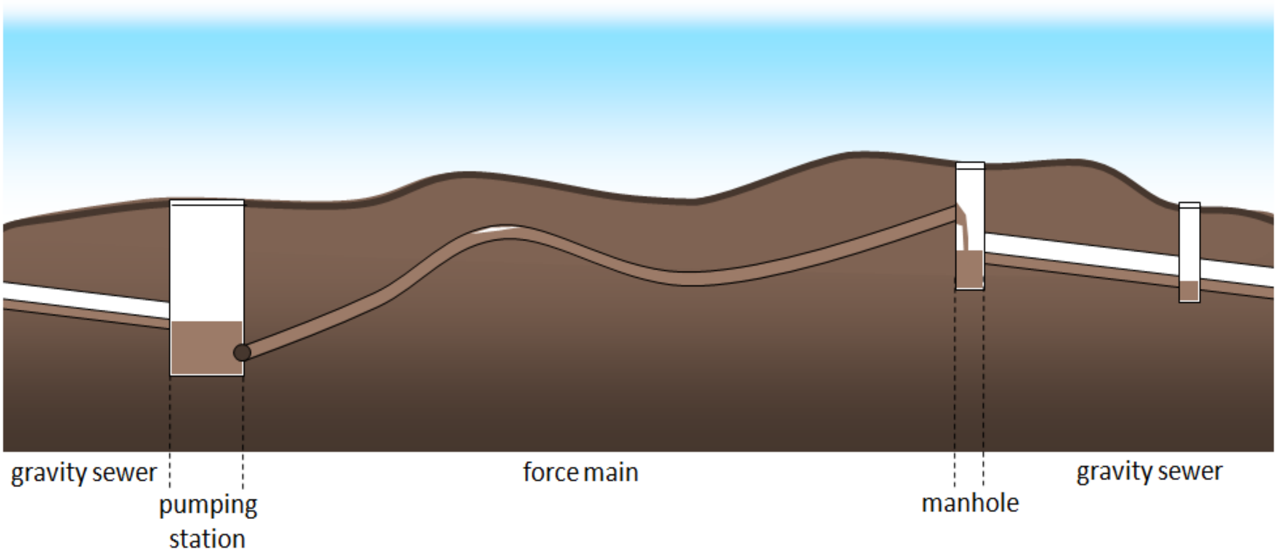


Figure 1: Schematic representation of a simplified, conventional wastewater collection system, illustrating its most common constituents.

As stated above, many problems arise in the sewer infrastructure as a result of the presence of hydrogen sulfide. This molecule is formed under anaerobic conditions, which in this context can be interpreted as conditions where oxygen is absent. Such conditions can occur at different places in the sewer infrastructure, such as:

- force mains;
- completely filled gravity sewers;
- slow-flowing, partially filled gravity sewers;
- biofilm and sediment layers found in gravity sewers;
- inverted siphons, which are sometimes used to pass rivers or other deep obstructions without the need for pumping;
- wet well of pumping stations and other places where the wastewater might stand still for a significant amount of time;
- ...

When present in the sewer atmosphere, for instance, hydrogen sulfide will initiate a process called biogenic sulfuric acid corrosion, where the concrete sewer pipes corrode and lose their mechanical strength. In addition, malodorous compounds such as hydrogen sulfide are typically formed under the same anaerobic conditions and thus contributes to odor nuisance.

In this paper, however, only corrosion problems are dealt with. More precisely, the many scientific papers on this subject will be illustrated with examples from the sewer infrastructures managed by Aquafin. In addition, this paper will elaborate on how to proceed when confronted with sulfide-induced corrosion, based on the experiences gained from a case study.

SULFIDE FORMATION AND SULFIDE-INDUCED CORROSION

Given the enormous value of the assets that are potentially exposed to these hydrogen sulfide related problems worldwide, it is not surprising that these issues have been the subject of many research programs in the past decades. These efforts increased the know-how concerning sewer processes and resulted in some mathematical models used by engineers dealing with these problems (Hvitved-Jacobsen, 2002; Sharma *et al.*, 2008; Weismann and Lohse, 2007).

The formation and fate of sulfide in wastewater collection systems is governed by a large number of complex and interrelated processes (Pomeroy and Parkhurst, 1977; Nielsen *et al*., 2006). Because a detailed discussion of these processes is beyond the scope of this paper, only the most relevant are briefly described below. For more detailed information, the reader is referred to the cited references.

a) Formation of hydrogen sulfide

Sulfide is produced by heterotrophic, anaerobic bacteria using sulfate as terminal electron acceptor when growing on the organic matter present in the wastewater (Hvitved-Jacobsen, 2002). Since these bacteria are typically slow-growing (Nielsen *et al*., 2006), this process mainly takes place in the biofilm (the sewer slimes) and sediments covering the submerged sewer walls. After diffusing to the wastewater stream, the sulfides are readily oxidized by chemical and biological processes when dissolved oxygen is present. However, when the dissolved oxygen levels are insufficient or insignificant, sulfide will accumulate in the wastewater and sulfide concentrations may become potentially harmful. This, for instance, occurs in force mains with a long retention time, but also in slow-flowing, partially filled gravity sewers or other parts of the sewer mentioned in the introduction of this paper.

b) Corrosion of ductile iron force mains

About 12% of the force mains operated by Aquafin are constructed in ductile iron, most of which are quite old and were inherited by Aquafin. When significant sulfide concentrations are obtained in these ductile cast iron pipes, the iron will react with hydrogen sulfide and insoluble iron sulfides (FeS) will be formed (metal corrosion). These FeS molecules will deposit in the pressure main and a thick black layer of sludge is deposited (two examples are depicted in Figure 2). As a consequence, also the mechanical strength of the pipe will decrease as iron is gradually leached out. The pipe becomes thinner and groundwater infiltrations may be expected.

Figure 2: Illustrating the effect of hydrogen sulfide in a cast iron pressure main in Flanders (Belgium).

c) Biogenic sulfuric acid corrosion of concrete pipes

Although the deterioration of ductile iron force mains is a significant problem, the most important form of corrosion in the sewer infrastructure is the so-called biogenic sulfuric acid corrosion. This occurs in concrete pipes, that are mostly used for collector sewers, but also when air pockets occur in force mains constructed in asbestos cement (Smolder *et al*., 2009).

When hydrogen sulfide occurs in the water phase, no harmful effects will be observed (Hvitved-Jacobsen, 2002), but once it is emitted to the sewer atmosphere the corrosion process will take place. This emission process is significantly enhanced at special sewer structures like bends, junctions, manholes, weirs and drops, all of which give rise to excessive turbulence significantly enhancing the liquid-water transfer of hydrogen sulfide.

When the sulfide enters the sewer atmosphere of gravity sewers, it will rapidly absorb onto the moist surface of the unsubmerged, upper part of the sewer wall, where it is consumed by the biofilm in which aerobic bacteria from the *Thiobacillus* family produce sulfuric acid (Sand 1987, Hvitved-Jacobsen, 2002), lowering the pH significantly (pH levels of 1 are not exceptional). These bacteria are able to grow at pH levels between 0.5 and 5 (Hvitved-Jacobsen, 2002 Under such conditions, the sulfuric acid reacts with calcium present in the cement to form gypsum and ettringite and leaving a material of loose bound inert components, e.g. sand and gravel, without any mechanical strength (shown in Figure 3). Eventually, the concrete sewer pipe may collapse.

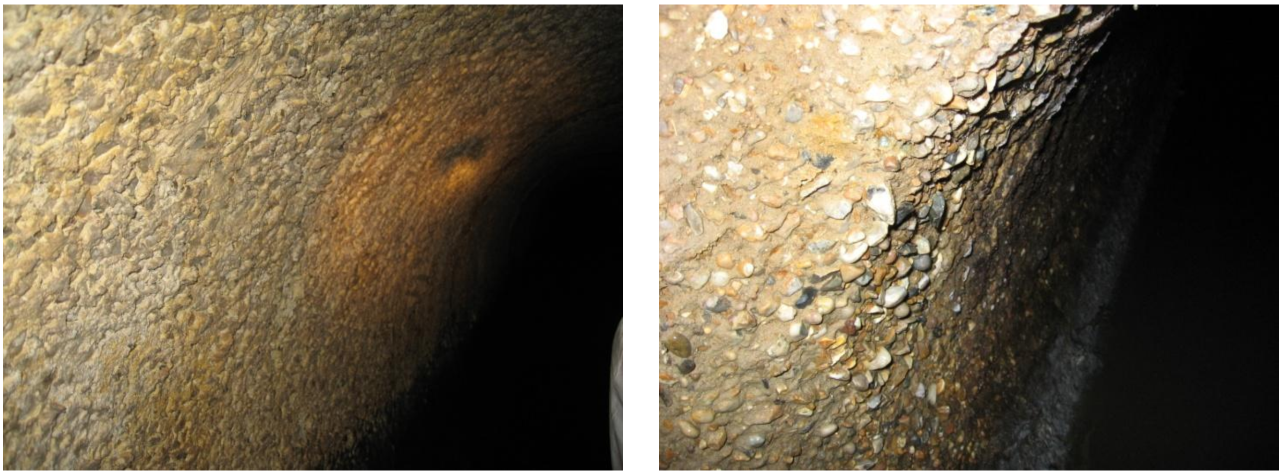
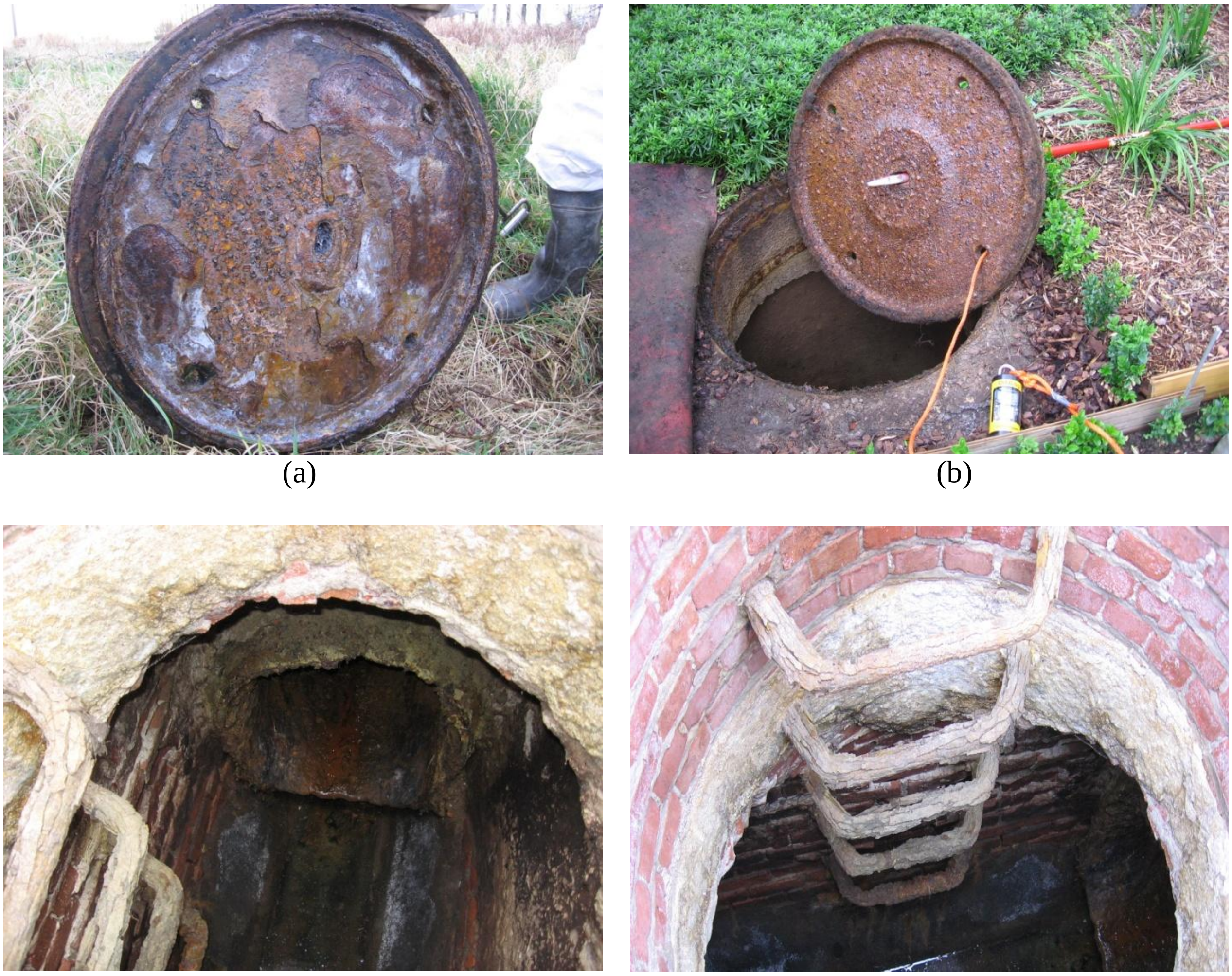


Figure 3: Illustrating the effect of hydrogen sulfide-induced concrete corrosion in a collector sewer in Flanders (Belgium).

d) Damage to inspection chambers or manholes

Inspection chambers or manholes are usually built in concrete and covered with a cast iron lid. The manhole in which the wastewater from a force main is discharged, as well as the manholes further downstream may also be exposed to significantly high concentrations of sulfide. Indeed, as this discharge is usually accompanied with a lot of turbulence, a significant fraction of the hydrogen sulfide gas present in the wastewater will be emitted to the sewer atmosphere. As it absorbs in condensate present on the iron lid and on the concrete walls of the manhole and the gravity sewer downstream, corrosion problems will arise (as illustrated in Figure 4).



(a) (b)

(c) (d)

Figure 4: Illustrating the effect of hydrogen sulfide on cast iron lids covering of manholes (a-b) and ladders (c-d).

TOWARDS A FRAMEWORK FOR DEALING WITH SULFIDE PROBLEMS

In many cases, problems related to the presence of hydrogen sulfide in sewer systems become apparent only after receiving complaints about odor or when damage as a result of biogenic sulfuric acid corrosion is observed during (occasional) inspections. When confronted with such problems, it is of crucial importance to promptly (re)act in the most appropriate way. Today, dealing with odor or corrosion problems is often done in an *ad hoc* manner, as there is no generally accepted framework allowing to deal with odor and corrosion problems in sewer systems in a systematic way (at least not to our knowledge).

Of course, an operator such as Aquafin should try to avoid corrosion problems through proper design, operation and maintenance of the sewer systems, but problems cannot always be anticipated or prevented. In this respect, the question of how to deal with corrosion problems is extremely relevant. In this section, the lessons drawn from a case study will be discussed and some conclusions will be formulated to take into account when developing guidelines to tackle corrosion problems in a systematic manner.

a) Description of the case study

During the inspection of a collector sewer of approximately five years old, severe damage to the concrete pipe was observed that could be attributed to biogenic sulfuric acid corrosion. Since an inspection held one year earlier did not reveal significant corrosion, the loss of wall thickness (which was estimated to be in the order of a few centimeters) occurred in a time span of approximately one year and the corrosion rate could thus be considered as very high. Since the collector sewer (with a diameter of 1600 mm and an original wall thickness of 13.5 cm) transports the wastewater of a large part of a Flemish city (±250.000 IE), it can be considered as strategically important and the situation was dealt with immediately.

The collector (represented by the orange arrow in Figure 5) receives wastewater from a force main (the dashed red arrow) that originates at pumping station PS1 that was operational for only two years at the time of inspection. In addition, the wastewater of the city center is collected through gravity sewers (indicted by green lines) discharging in the collector at several locations, each of which is indicated in Figure 5) with a corresponding label Kx. Eventually, a pumping station downstream of the collector (PS2) pumps the sewage to the wastewater treatment plant.

Because the most severe corrosion problems were observed in the upstream part of the collector (between K8 and K6) and because immediate action was requested by the management, dosage of calcium nitrate at pumping station PS1 was started as soon as possible. Indeed, our first guess was that the sulfides were formed in the force main, which is quite often the case, and dosing nitrate is common practice to suppress sulfide formation in force mains (Bentzen *et al.*, 1995, Hvitved-Jacobsen, 2002). Still, some things were unclear at that time:

- The hydraulic retention time in the force main was estimated to be more or less one hour on average, which is relatively short and generally considered as too short to be harmful.
- A report of earlier in time, prior to the detection of the corrosion problems, already stated that the dissolved concentrations in the wastewater arriving at pumping station PS1 (so before the force main) were significant, but this could not be explained at that time and it was (incorrectly) suggested that an industrial discharge was responsible.
- Relatively high sulfide concentrations were also measured in the wastewater from the gravity sewer under the city center.

These issues were further investigated in the succeeding months and during this investigation (which was a typical example of *ad hoc* problem solving), increased knowledge was gained which could eventually contribute to the development of guidelines to deal with such problems in a more systematic way.

b) Knowledge of the processes of sulfide formation and biogenic sulfuric acid corrosion

The different biological and chemical processes occurring in the sewer system are very complex and interrelated. Although several knowledge gaps remain (WERF, 2007), it is important to be familiar with the most important concepts in order to organize measurement campaigns properly, to identify possible sources of sulfide in the sewer infrastructure and to interpret the collected data sets. Good starting points are the books of Hvitved-Jacobsen (2002), the one edited by Weismann and Lohse (2007) and the US EPA reports mentioned in the references.

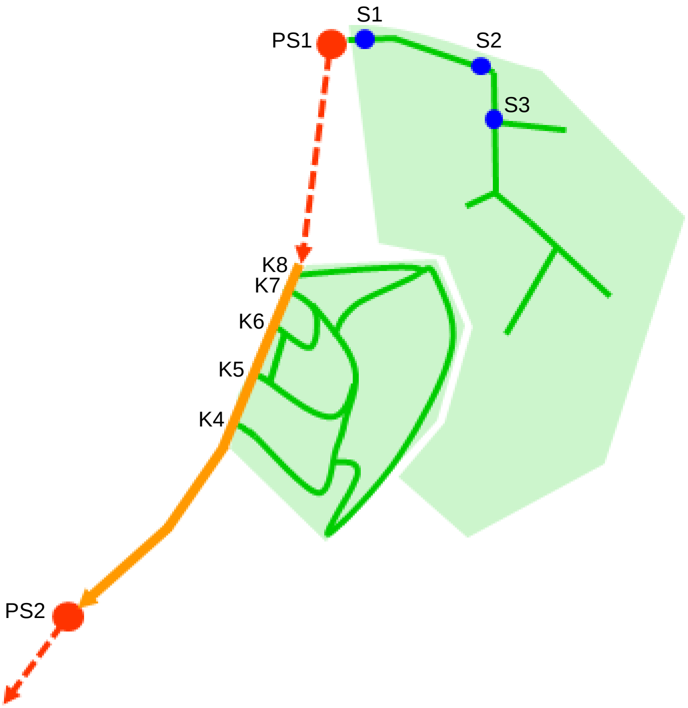


Figure 5: Schematical representation of the case study, where the collector sewer is represented by the orange arrow, the force mains by the red, dashed arrows and the pumping stations are indicated as ‘PS’. The gravity sewers are shown in green and the discharge points in the collector are labelled as ‘Kx’.

c) Inventory of corrosion problems

When corrosion is observed at one location, it is plausible that other parts of the sewers are corroded as well. Therefore, it is advisable to do inspections in the up- and downstream parts of the sewer infrastructure. Not only in view of a possible refurbishment of the sewer, but also to contribute to a better understanding of the different aspects of the problem.

In the presented case study, for instance, the wet well of the pumping station showed early signs of corrosion and in the past, some corrosion was observed at discharge point K5 (see Figure 5), which at that time resulted in the application of a protective coating of the manhole. Such information is very important, because it can guide us to the sources of the sulfides and help us in designing measurement campaigns

d) Sulfide measurements: what can be measured and what do we learn from it?

In order to get insight in the situation (and, eventually, to tackle the problem at hand), it is essential to perform dedicated measurement campaigns during which the dissolved sulfide concentrations in the wastewater as well as the concentrations in the sewer atmosphere are measured. Indeed, when formed, hydrogen sulfide dissolves in the wastewater and part of it will gradually be emitted to the sewer atmosphere. As this emission process is much more pronounced in the presence of turbulence, most of the problems are found after drop structures, bends or other turbulent parts of the sewer infrastructure. The locations where corrosion is manifested are thus in general not the locations where sulfide is formed, and making an inventory of the corroded parts of the sewer system is therefore not enough.

To determine the sources of hydrogen sulfide, grab samples of the wastewater are analyzed using the methylene blue method (APHA, 1995). Although it is not always straightforward to take representative grab samples in practice, these measurements are highly informative. The sulfide concentrations in the sewer atmosphere, on the other hand, can be measured continuously using commercially available sensors.

Other parameters such as biological oxygen demand, pH, dissolved oxygen, temperature, sulfate concentration or oxidation-reduction potential (ORP) are, of course, informative as well, but it is not always feasible to measure them in sewers, where the supply of electricity, for example, is hardly ever guaranteed. Also note that the applicability of an online spectrophotometric measurement of sulfide has recently been tested successfully by others (Sutherland-Stacey, 2008), which allows a continuous measurement of the dissolved sulfide concentration in wastewater. Since the latter is known to vary significantly (Hvitved-Jacobsen, 2002), this is much more informative than analyzing grab samples.

e) Knowledge of the sewer infrastructure

In the presented case study, it was clear almost from the beginning that a relevant fraction of the hydrogen sulfide must have been formed upstream of the force main (sulfide-rich wastewater at entrance and early signs of corrosion in wet well). After carefully investigating the upstream sewer infrastructure it was found that the wastewater arriving at pumping station PS1 passed three inverted siphons that were constructed in the 1930’s (indicated by S1, S2 and S3 in Figure 5). When designing and constructing the pumping station, these siphons were not considered important or problematic, because the design primarily focused on hydraulic aspects. However, they have now been identified as the core of the corrosion problems in the collector further downstream.

Indeed, the results of a measurement campaign (shown in Figure 6) clearly indicate a significant increase in the sulfide concentrations after an inverted siphon. Since the hydraulic residence time in these siphons is quite low (estimated to be less than half an hour), the latest hypothesis is that these siphons must act as a bioreactor that is continuously enriching the wastewater with sulfides. This hypothesis is to some extent in accordance with theory, because a lot of sediments have accumulated in the siphons over the years and this layer of sediments is believed to act as a thick, anaerobic biofilm.

Also, the corrosion problems dealt with in the past at discharge point K5 (Figure 5) indicated that sulfides are formed in at least part of the gravity sewers as well. The latter was confirmed after performing a measurement campaign (Figure 7), and further investigations showed that (also here) a lot of deposits are found in the sewers. The relatively small diameter of the sewer pipes, their low slope and the fact that a lot of restaurants are connected to the K5-branch were identified as the root causes.

These examples demonstrate that sulfide formation not only occurs in force mains, and that the sources are not always apparent at first. In the presented case study, for instance, several parts of the sewer infrastructure were built in the beginning of the previous century and the information is often scarce or even unavailable. Still, this kind of information is essential to screen the upstream parts of the sewer infrastructure for potential sources of hydrogen sulfide and to organize dedicated measurement campaigns.

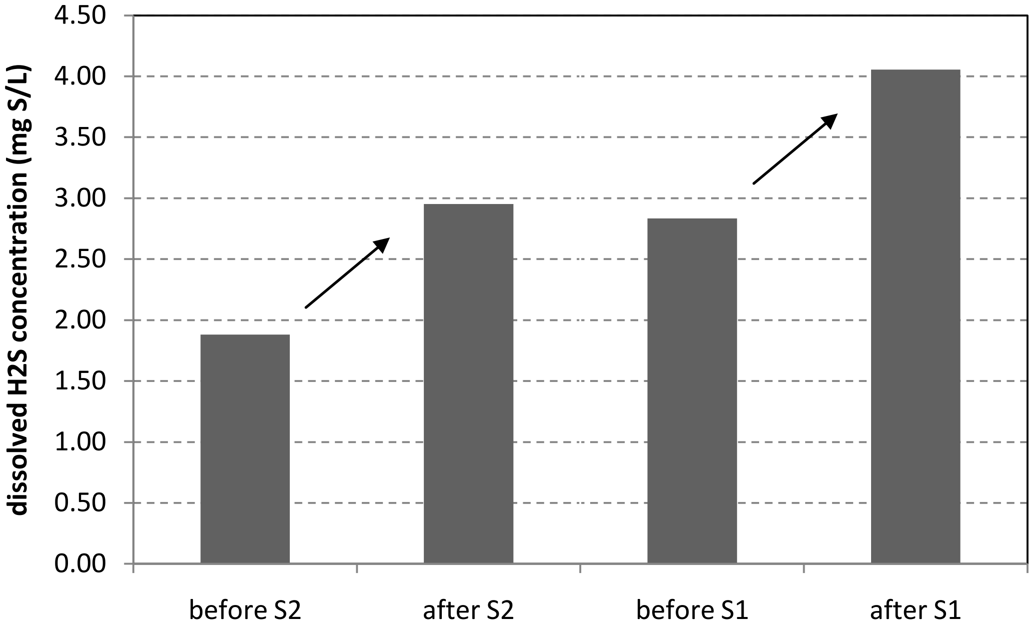


Figure 6: Results from a measurement campaign in which the dissolved sulfide concentrations were measured before and after two inverted siphons (S1 and S2).

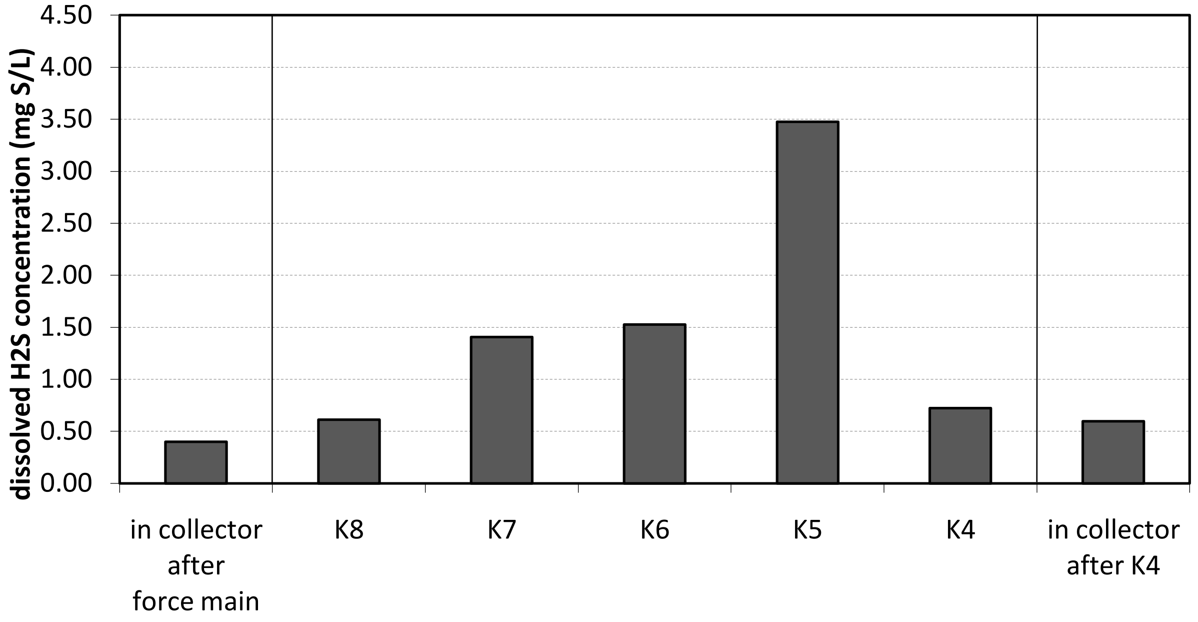


Figure 7: Results from a measurement campaign in which the dissolved sulfide concentrations were measured in the wastewater coming from the force main, the different branches of the network of gravity sewers under the city center and in the collector after discharge point K4.

CONCLUSIONS

Problems with sulfide-induced corrosion are very difficult to avoid and when damage to the sewer infrastructure is observed, immediate action is often required. In order to take the most appropriate measures, a good insight into the situation is crucial. Today, these kind of problems are typically dealt with in an *ad hoc* manner, but a framework to systematically and efficiently deal with these problems would definitely be a merit.

In this paper, a case study was described and the lessons drawn from it should aid in the development of such a framework. To get insight in the different aspects of the problem, carefully designed measurement campaigns have to be performed and for this it is important (1) to be familiar with the most important processes that occur in sewers, (2) to gather information about the sewer system in order to screen it for potential sources of hydrogen sulfide, and (3) to make an inventory of other corroded locations in the relevant part of the sewer infrastructure.

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