

Monitoring CO² and H₂S Emission in Live Austrian and UK Concrete Sewer Pipes

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Abstract—Corrosion of concrete sewer pipes induced by sulfuric acid is an acknowledged problem and a ticking time-bomb to sewer operators. Whilst the chemical reaction of the corrosion process is well-understood, the indirect roles of other parameters in the corrosion process which are found in sewer environment are not highly reflected on. This paper reports on a field studies undertaken in Austria and United Kingdom, where the parameters of temperature, pH, H₂S and CO² were monitored over a period of time. The study establishes that (i) effluent temperature and pH have similar daily pattern and peak times, when examined in minutes scale; (ii) H₂S and CO² have an identical hourly pattern; (iii) H₂S instant or shifted relation to effluent temperature is governed by the root mean square value of CO².

Keywords—Concrete corrosion, carbon dioxide, hydrogen sulphide, sewer pipe, sulfuric acid.

I. INTRODUCTION

HYDROGEN sulphite build up in sewers is a dominating factor of sewer corrosion and in combination with a range of pipe flow rates, flow levels, flow dynamics & turbulence, effluent temperature, effluent chemical compound, pipe material alkalinity, soil movements and external loads it can have a drastic effect on pipe corrosion and premature failure.

In sewer pipes the microbially induced concrete corrosion (MICC) occurs as the *Acidithiobacillus thiooxidans* class of bacteria converts sulphate to sulphide in the effluent biofilm [1]. During this process some part of sulphide is released in atmosphere as gaseous hydrogen sulphide which is then oxidised to sulphuric acid [2]. This acid is usually formed on the concrete surface above the effluent. To better understand the chemical corrosion process and prevent pipes early disfunction a number of studies have been carried out which suggested that corrosion may establish slowly and as a by-product produce incrustation and gypsum [3] and when established, quickly accelerate to cause pipe wall and particularly pipe crown loss [4]. Experimental study suggested that corrosion process accelerates when surface pH values are below 4 [5] and [6], gas temperature is in range of 10-30°C and H₂S is at 3-400ppm [7] and [1]. Other works confirmed that the corrosion progresses more aggressively if the wall and pipe crown are flushed from time to time with excess flow

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removing previous corrosion layer flocks [8] and if there are evidence of turbulence and constant release of H₂S gas [1]. Additionally, it was suggested that presence of CO² may supplement surface pH reduction in early stages of corrosion which is further dominated by H₂S [9].

This paper presents CO² and H₂S data captured in four sewer manhole chambers located in Austria and UK, where the data was recorded over few days in June & July respectively, to establish a possible relation between the emission levels of hydrogen sulphide and carbon dioxide. The findings should further supplement the understanding of individual pipe corrosion levels and acceleration over time.

II. FIELD EXPERIMENTS

A. Austrian Sites

The field experiments in Austria took place west of Vienna in a town of Neulengbach, where two manholes with concrete pipes that had small corrosion levels were selected. One of the pipes (Manhole 1) was a main collection sewer, transporting wastewater from the city into sewer treatment plant, which was located 2km downstream. Other pipe (Manhole 2) was located in quiet residential road collecting wastewater from a number of private houses, nursery and a small hospital. This manhole had a house connection direct in the manhole chamber. Pipes in Manhole 1 and Manhole 2 were of 600mm and 300mm in external diameter, respectively.

B. United Kingdom Sites

In the United Kingdom two live concrete sewer pipe sections were selected for experiments, which were known to suffer from corrosion. Both pipes were located in South East of London, in Chattenden residential area (Manhole 3) and Mote Park in Maidstone (Manhole 4). An access to each of the pipe sections was granted via manhole entry. In each of the manholes apart from the main sewer line a pumping station discharge connection was located. Manhole 3 was located 4676m, 2415m and 2037m downstream from three pumping mains. Manhole 4 was located 2572m downstream from pumped main and 336m away from discharge manhole. Even though the pipe within Manhole 4 was located in the park area, it transported water from industrial and residential estates. Both of the pipes were of 300mm in external diameter.

C. Equipment

To monitor the parameters in each of the manholes a temperature and pH data sensor (pHTemp101, Madgetech) as well as H₂S (BT GasAlert Extreme IR, EGM) and CO² (BT GasAlertMicro5 IR, EGM) were used, sampling at 5min, 2min

and 2min respectively for a period of 24h. All of the sensors were securely positioned in the sewer manhole chamber above the effluent. The temperature and pH of the effluent were monitored through the extended thermocouple and pH electrode, where both of them were fully submerged by the flow and the logger was placed in the water proof case. The H₂S and CO₂ were measured in the air phase, 400mm above the effluent inside the manhole chamber. Fig. 1 shows the typical arrangement of the equipment in the manhole chamber.



Fig. 1 Equipment setup in a sewer manhole chamber

III. DATA MONITORING

A. Flow Depth and Velocity

For each of the Manholes 1-4 the flow depth and velocity were recorded at three stages of the 24h monitoring process, at 10am, 4pm and 8pm. The average values of all three parameters were recorded for reference. In columns from left to right, Table I presents values of manhole number, pipe internal diameter, pipe bed slope, average corrosion level, effluent flow depth, effluent flow depth occupation as a percentage of pipe diameter and flow velocity.

TABLE I
PIPE AND FLOW PARAMETERS

No	Manhole 1	Manhole 2	Manhole 3	Manhole 4
<i>D</i> [mm]	580	265	265	265
<i>s</i> [%]	3	1	2	4
<i>C</i> [mm]	6	4	15	11
<i>h</i> [mm]	280	45	160	110
<i>h</i> [%]	64	17	60	3.1
<i>u</i> [l/s]	3.7	1.9	3.1	2.6

B. Effluent Temperature

The temperature of effluent in manhole chambers, as investigated earlier, is a function of effluent temperature and outside temperature of air [10], where the effluent temperature hourly pattern is governed by the households and industry daily activity and general temperature trend is dictated by the outside temperature of air and intruding storm water during rain events. In current field trials the mean daily temperature for Manholes 1-4 was 14, 19, 19 & 22C° respectively. Fig. 2 shows the effluent temperature pattern for Manhole 2 (Austria) and Manhole 3 (UK) for 24h. It can be noted that despite the difference in geographical location and areas where the manholes were located, the temperature seems to

increase predominantly between 5-8pm for Austria and UK manholes, which is the time when people return home from work, prepare meals and use bath/shower facilities. Additionally, temperature increases in the morning hours for the UK manholes between 7-9am which is when people have their morning meals and get ready for school and work. In Austria this morning pattern is not recorded as they massively utilise a variety of small systems for grey water re-use, which keeps the direct water discharge into sewer system at minimum during low to medium water consumption hours. During peak hours, the storage for grey water is full and hence increased discharge into sewer systems is recorded. Tables II and III summarise temperature values for all manholes.

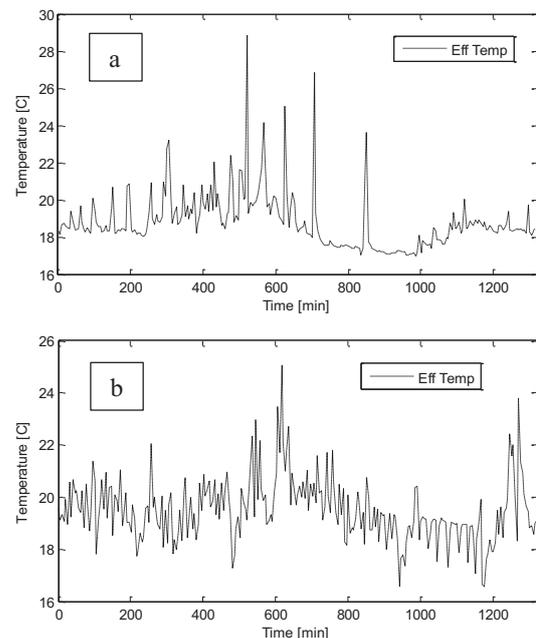


Fig. 2 Effluent temperature for Manhole 2 (a) and Manhole 3 (b), shown in minutes with zero set at 7am

C. Effluent pH

In previous study which took place in Feb-Apr period of 2014 in Manholes 3 & 4, it was shown that pH value fluctuates in region of 6.7-7.1 with little variation [10]. This was thought to be related to large concentration of fats and oil in the effluent. The data obtain in current trials demonstrated a pH fluctuation in range of 6.4-10.2 between all 4 manholes. Fig. 3 demonstrates pH values fluctuations for 24h period recorded in Manhole 2 (Austria) and Manhole 3 (UK). After the deployment of the pH electrode into the effluent it takes about an hour for the electrode to stabilise, hence these values were removed from the statistical data presented in Tables II and III in section on results.

D. Hydrogen Sulphite

Hydrogen sulphate gas concentrations for Manhole 3 & 4 (both located in UK) for a period of 13h are shown in Fig. 4. Manhole 3 shows steady increases of H₂S gas over 12h with intermediate peaks of 60-110ppm and a major peak of 150ppm at 9pm, which further declines up until early morning hours of

3-6am. Manhole 4 has slightly different daily pattern of H₂S concentration, and on average the H₂S peak values are around 25-40ppm. As confirmed before [10], for these locations the H₂S build up is highly governed by the discharges of the local pumping mains. The statistical values for the H₂S are shown in Tables II and III.

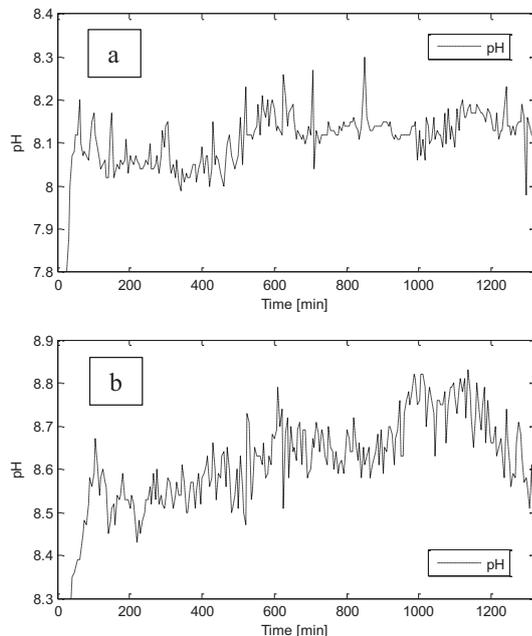


Fig. 3 pH for Manhole 2 (a) and Manhole 3 (b), shown in minutes with zero set at 7am

Unexpectedly, for Austrian manholes the H₂S gas level for both of the manholes in subsequent 24 hours identified 0. The sewer operator from AWV Anzbach-Laabental explained that they add a number of chemicals to kill the odour caused by hydrogen sulphite during the summer period as the local residents were continuously complaining about it in the past. However, there was no information on chemical compound or how this chemical reacts in process of production of H₂S.

E. Carbon Dioxide

Fig. 5 shows the carbon dioxide concentration for Manhole 1 (Austria) and Manhole 3 (UK) for a period of 10h and 13h, respectively. For Manhole 1, between 7am and 9pm the CO₂ values are relatively low, at 280ppm on average, however there is a sharp peak of 3200ppm which is difficult to explain. After 9pm the CO₂ value rapidly increases to 1600ppm and continue to slowly grow reaching 3000ppm by 7pm. At 4:30pm there is a sharp decrease of CO₂ value reading 700ppm, which again falls out of a general trend. On other hand, Manhole 3 shows steady increase of CO₂ with time and reaches peak of 3900ppm at around 9:30pm which is somehow similar to Manhole 1, and indicates a CO₂ build-up during the day with peak values being in the evening hours. The statistical data for CO₂ is shown in Tables II and III.

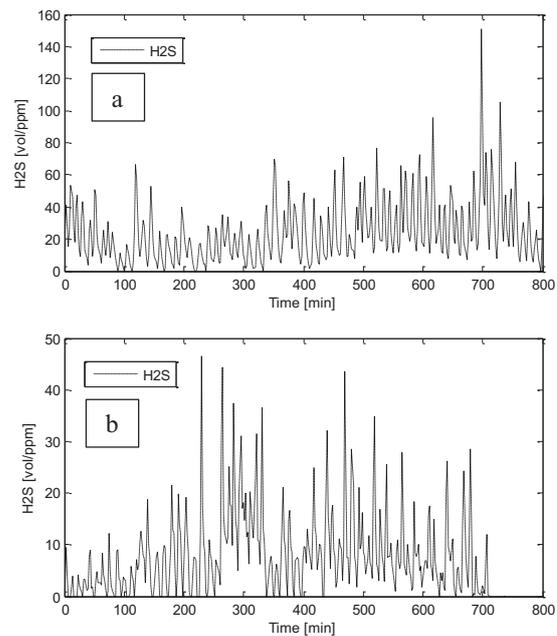


Fig. 4 H₂S concentration for Manhole 3 (a) and Manhole 4 (b), shown in minutes with zero set at 7am

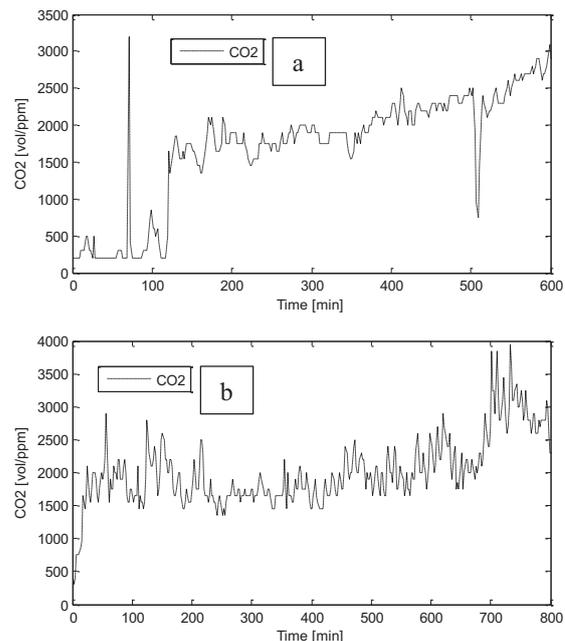


Fig. 5 CO₂ concentration for Manhole 1 (a) and Manhole 3 (b), shown in minutes with zero set at 7am

IV. RESULTS

A. Parameter Statistics

Tables II and III present the maximum, minimum, mean and root mean square (rms) values for Manholes 1-4 data of temperature, pH, H₂S and CO₂, for Austria and UK, respectively. On average the mean of all parameters is higher for UK sites than for Austria, whereas rms values vary from manhole to manhole.

TABLE II
PARAMETERS STATISTICAL DATA FOR AUSTRIA

A	Manhole 1				Manhole 2			
	T	pH	H ₂ S	CO ₂	T	pH	H ₂ S	CO ₂
Max	16.54	8.01	0	3850	28.87	8.30	0	600
Min	14.10	6.40	0	200	16.95	7.18	0	200
Mean	14.56	7.83	-	2134	18.82	8.09	-	451
rms	0.39	0.21	-	707	1.52	0.11	-	60

TABLE III
PARAMETERS STATISTICAL DATA FOR UK

UK	Manhole 3				Manhole 4			
	T	pH	H ₂ S	CO ₂	T	pH	H ₂ S	CO ₂
Max	25.05	8.83	213	7200	23.62	10.23	47	5400
Min	16.55	7.72	0	300	20.53	8.03	0	750
Mean	19.46	8.60	27	2369	21.91	8.64	6.4	2793
rms	1.16	0.10	25	724	0.75	0.39	8	1287

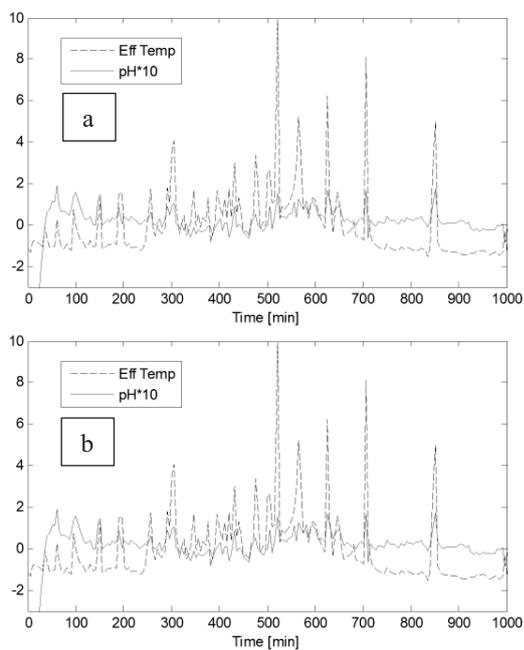


Fig. 6 Detrended & scaled effluent temperature and pH for Manhole 2 (a) and Manhole 3 (b), shown in minutes with zero set at 7am

B. Parameter Relation

The detrended values of effluent temperature (where mean values were set to zero) and pH values (scaled by a factor of 10), monitored in Manholes 2 (Austria) and Manhole 3 (UK) for a period of 17h, are shown in Fig. 6. For both of the manholes, the data clearly identifies that there is an instant response between effluent temperature and pH as their general hourly trend and peak patterns superimpose. This result is unforeseen and requires in depth explanation of how the given physical and chemical parameters interact.

Further, Fig. 7 demonstrates the H₂S and CO₂ concentration values, for a period of 23h and 14h for Manhole 3 and 4 (both in the UK), respectively. The data on these graphs was detrended, normalised by maximum values and reshaped to hours. From both of the graphs it is visible that there is a relation between H₂S and CO₂ perturbations, which is more

strongly pronounced in Manhole 3. Compared to Manhole 4, Manhole 3 is under higher impact of pumping mains and carries daily more flow.

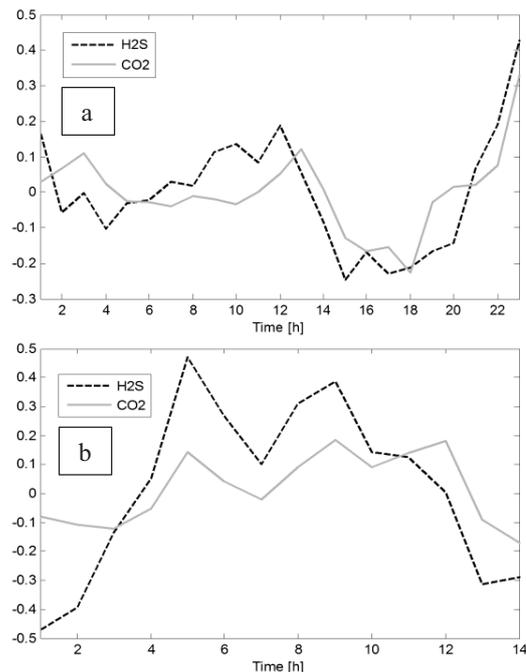


Fig. 7 Normalised by maximum, H₂S and CO₂ concentration for Manhole 3 (a) and Manhole 4 (b), shown in hours with zero set at 7am

Finally, Fig. 8 illustrates the detrended, normalised by maximum H₂S and effluent temperature data, where the last was also scaled by a factor of 2 and 10, for Manholes 3 & 4 respectively. In Fig. 8 the data is also reshaped to hours and presented for 23h and 14h. It can be noted that for Manhole 3, the H₂S has an instant response to change in temperature. This was not spotted before, and in fact in earlier study a shift of approximately 10h between H₂S response to temperature was observed [10]. Whereas for Manhole 4, the shift effect between data persists. This discrepancy in behavior is thought to be governed by the instant concentration of CO₂ in the gas phase of the manhole chamber. The data shows that with higher rms value of CO₂ the more shift is imposed on H₂S data with regards to effluent temperature. However, with CO₂ rms of app. 700ppm the H₂S has an instant response to effluent temperature variations analysed in hourly domain.

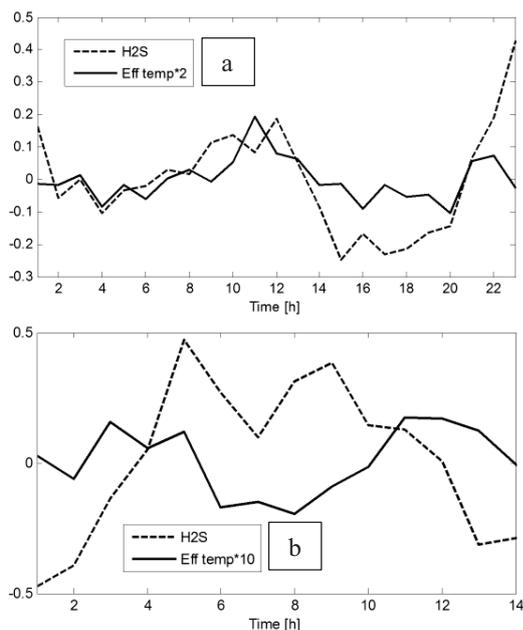


Fig. 8 Normalised by maximum, & scaled H₂S and effluent pH for Manhole 3 (a) and Manhole 4 (b), shown in hours with zero set at 7am

V. CONCLUSIONS

The 24h data monitoring study, focusing on effluent temperature, pH, H₂S and CO₂, carried out in summer 2014 in four sewer pipes chamber manholes, with two manholes located in Austria and UK, revealed the following:

1. Effluent temperature and pH have similar daily pattern and peak times, when examined in minutes scale;
2. H₂S and CO₂ have an identical hourly pattern;
3. H₂S instant or shifted relation to effluent temperature is governed by the root mean square value of CO₂.

Given the results of this study, further closer monitoring of the above parameters is required to carry out systematic correlation analysis for effluent temperature and pH, as well as H₂S and CO₂. Longer time series data will enable to perform the statistical analysis to establish the length of H₂S shift in relation to effluent temperature, as well as those based on the root mean square values of CO₂. A long term monitoring for these manholes will be continued to give a representative all year round statistics of temperature, pH, H₂S and CO₂ parameters, which is believed to be necessary in order to better understand the corrosion process in pipes such that the corrosion prediction models could be reliably calibrated.

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REFERENCES

- [1] J. Vollertsen, A. H. Nielsen, H. S. Jensen, T.W. Andersen and T. H. Jacobsen, "Corrosion of concrete sewers - The kinetics of hydrogen sulphide oxidation.," in *Science of the Total Environment*, 394, vol. 1, 2008, pp. 162-170.
- [2] C. D. Parker, "Mechanics of Corrosion of Concrete Sewers by Hydrogen Sulphide," in *Sewage and Industrial Wastes*, 23, vol. 12, 1951, pp. 1477-1485.
- [3] E. Vincke, N. Boon and W. Verstraete, "Analysis of the microbial communities on corroded concrete sewer pipes - a case study," in *Applied Microbiology and Biotechnology*, 57, vol. 5-6, 2001, pp. 776-785.
- [4] D. P. Kelly and A. P. Wood, "Reclassification of some species of Thiobacillus to the newly designated genera Acidithiobacillus gen. nov., Halothiobacillus gen. novand Thermithiobacillus gen. nov.," in *Systematic and Evolutionary Microbiology*, 50, 2000, pp. 511-516.
- [5] C. G. Jin and D. L. Won, *Master plan for joint pitfalls*, Rep. to Chf. Engr. And Gen. Mgr. Of County Sanit. Dist. Of Los Angeles, 1989.
- [6] A. H. Nielsen, J. Vollertsen, H. S. Jensen, T. Wium-Andersen and T. Hvitved-Jacobsen, "Influence of pipe material and surfaces on sulphide related odor and corrosion in sewers," in *Water Research*, 42, vol. 15, 2008, pp. 4206-4214.
- [7] H. Satoh, M. Odagiri, "Microbial community structures and in situ sulphate-reducing and sulphur-oxidizing activities in biofilms developed on mortar specimens in a corroded sewer system," in *Water Research*, 43, vol. 18, 2009, pp. 4729-4739.
- [8] A. H. Nielsen, J. Vollertsen, H. S. Jensen, H. I. Madsen and T. Hvitved-Jacobsen, "Aerobic and anaerobic transformations of sulphide in a sewer system - Field study and model simulations," in *Water Environment Research*, 80, vol. 1, 2008, pp.16-25.
- [9] A. P. Joseph, J. Keller, H. Bustamante and P. L. Bond, "Surface neutralization and H₂S oxidation at early stages of sewer corrosion: influence of temperature, relative humidity and H₂S concentration," in *Water Research*, 13, vol. 46, 2012, pp. 4235-4245.
- [10] A. Romanova, M. Mahmoodian and M. A. Alani, "Influence and interaction of H₂S, temperature and pH on concrete pipe corrosion process," in *Int. J. of Civil, Architectural, Structural, Urban Science and Engineering*, 6, vol. 8, 2014, pp. 592-595.