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THE UNIVERSITY OF SHEFFIELD

"CONCRETE CORROSION INDUCED BY SULFURIC ACID"

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ABSTRACT

Concrete sewer pipes are known to suffer from a process of hydrogen sulfide gas induced sulfuric acid corrosion. This leads to premature pipe degradation, performance failure and collapses which in turn may lead to property and health damage. To change the existing post-reactive attitude of managing companies, easy to use and robust models are required to be developed which currently lack reliable data to be correctly calibrated. This paper focuses on laboratory experiments of establishing concrete pipe corrosion rate by submerging samples into sulphuric acid solution for a duration of up to 120 days under 10-30ºC temperature regimes. The results showed that some samples at very early stage of the corrosion process gained overall mass and density with reverse process over time. Overall, in lab conditions the corrosion rates of 5-25mm/year were observed.

SEMINAR NOTES

1. Introduction

The Freedom of Information Act 2000 was used to gather the information from UK water companies on concrete pipe general statistics (age, diameter, wall thickness, average discharge, maintenance procedure, costs, repairs and collapses). Figure 1 shows the companies circled in red who have provided their responses.

Figure 1. Water companies in the UK who have provided their responses on concrete pipe statistics (circled red).

By reviewing the data it was concluded that there are 45,000km concrete sewers in total equating to £16B in assets, these cause an approximate 5,000 collapses per year costing £230M to the industry, where further 1,800 collapse incidents cause internal flooding costing additional £21M. Mainly, concrete pipes of 300-600mm in diameter in urban locations aged 20-30 years are at higher risk of collapse, with the main cause being sulphide corrosion.

The sulphite corrosion is known as Microbially Induced Concrete Corrosion (MICC). The bacteria class *Acidithiobacillus Thiooxidans* which are active in the effluent biofilm convert sulphate to sulphide. Some part of sulphide is released in atmosphere as gaseous hydrogen sulphide (H_2S). Further, the hydrogen sulphide is oxidised to sulphuric acid (H_2SO_4), which subsequently attacks susceptible pipeline materials (See Figure 2).
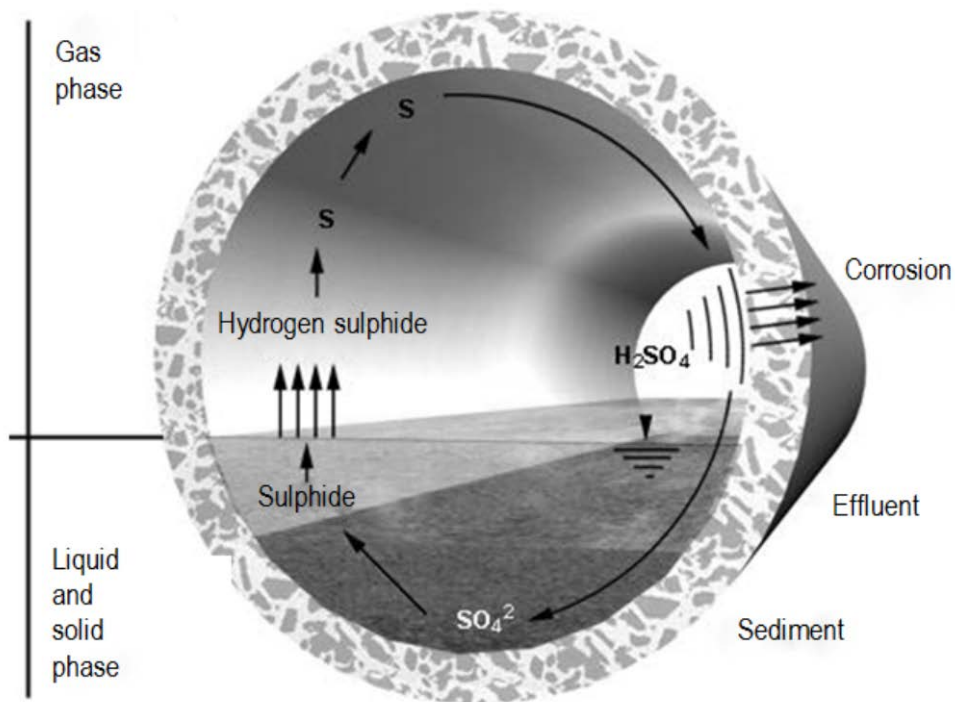

Figure 2. Microbially Induced Concrete Corrosion schematics.

Currently these are few things that are known about the corrosion process:

- Corrosion may establish slowly;
- Shows signs of dry incrustation;
- Provides for gypsum formation;
- Once established - accelerates rapidly;
- Occurs at the points of high turbulence (pipe crown);
- Accelerates when the surface is washed;
- Prefers constant release of H_2S, pH$<$4, $10<C^o<30$, $3<H_2S<400$.

2. Undertaken Work

The work was commenced in the laboratory and in the field, where the result of both activities it to create a validated model for probability of failure of concrete pipes (See Figure 3).
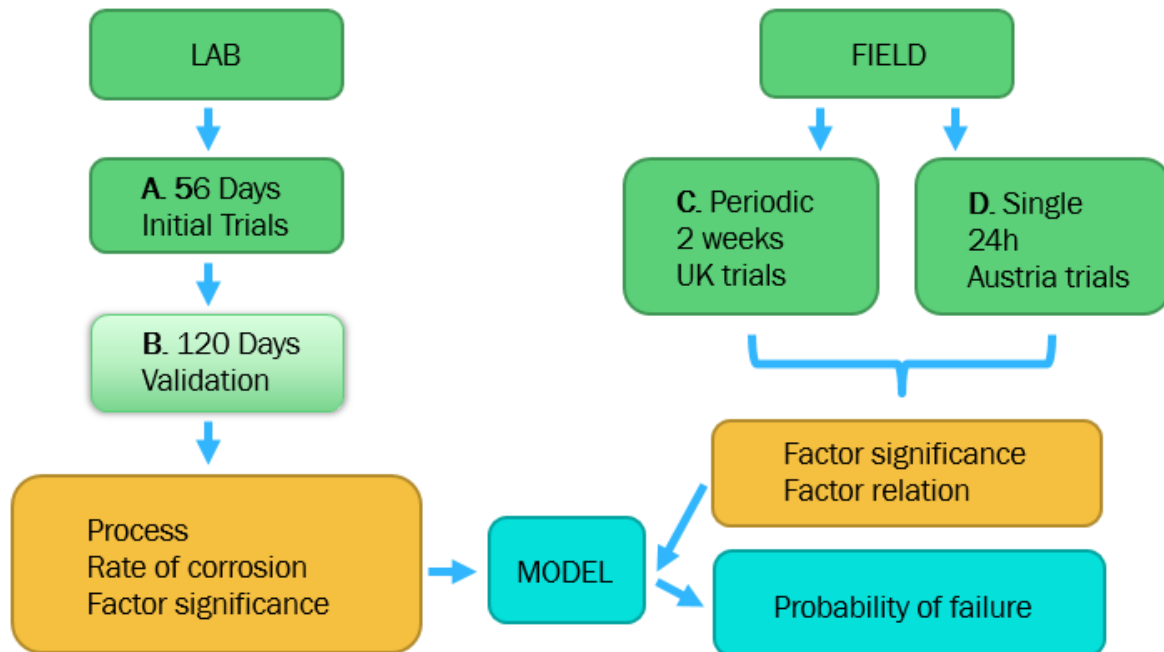

Figure 3. Packages and description of the comenced work.

2.1 Package A: Set-up

Experiments were conducted in a fully controlled environmental chamber located in Engineering Laboratory at the University of Greenwich.

The chamber hosted three curing tanks with further smaller submerged by 2/3 into the fluid create a thermal bath type effect and control a constant temperature of the 0.5pH sulphuric acid solution (See Figure 4). Three tanks: Tank 1, Tank 2 and Tank 3 maintained a constant temperature of solution located in containers of 10°C, 20°C and 30°C, respectively. The temperatures were chosen to represent the common range of effluent temperatures found in sewer pipes at different climate conditions.

A total number of 54 cubes, cut out from brand-new circular concrete pipe were used in these experiments. Each cube had a measurement of 100x100x100mm and was cut with diamond-blade rotating saw, however as

the process of cutting a circular pipe is very challenging and labour consuming a tolerance of 10% in each side measurement of the cube was allowed for.
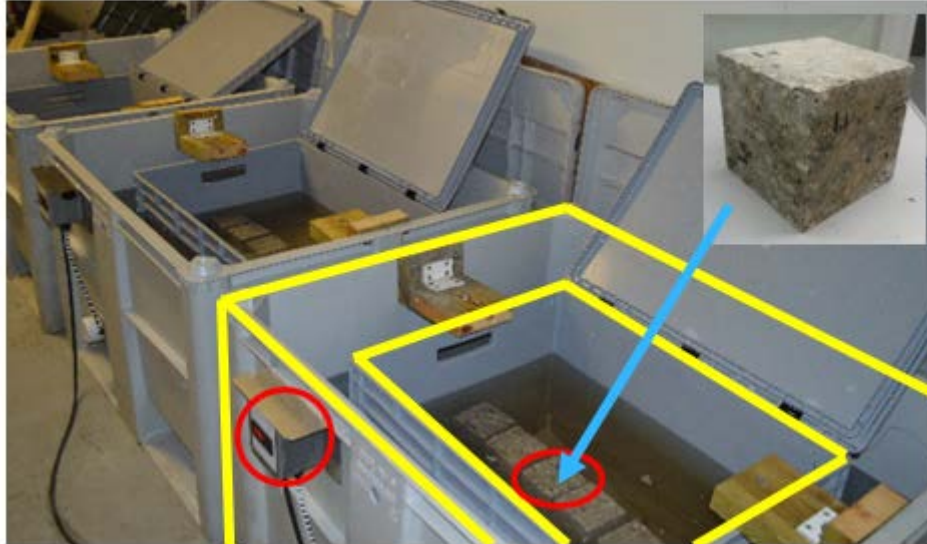

Figure 4. Curring tanks, container & cubes.

Before emersion into sulphuric acid solution each cube was dried in the industrial oven at 100°C for 24h. After the oven, the cube was left to cool for 2h at room temperature of 20°C. Further, the cube physical measurement of width, length and height were taken and their mass was recorded on weights (OHAUS I-10) which had a tolerance of 2g. The above data was further used to calculate the bulk density of the samples. Furthermore, the sample surface pH measurements were taken by the use of phenolphthalein to record any changes before and after emersion. A photogrammetry technique was used to recreate sample 3D structure before and after emersion and quantify the corrosion rate.

Each individual cube was numbered, immersed into sulphuric acid solution and ejected at 7, 14, 28, 42 and 56 days, in quantities of three from each tank. After ejection each cube was washed using tap water and gently brushed to remove any flocks. Further, they were placed in to the oven for another 24h at 100Co. After which the cubes were left to cool down for 2h and only then the physical measurements together with surface pH and photo tests were recorded.

A high resolution camera (Nikon D3200 SLR with 18-15 VR Lens) was used, where for each cube a picture at 45° angle to the top plane focusing on plane side was taken. These pictures were used to digitally estimate the roughness of the cube as a standard deviation of cube height from the edge-to-edge plane. A general view of the top plane of the cubes for different days of extraction is shown of Figure 5. In this study the calculated roughness was assumed to represent the level of corrosion. For each cube the corrosion depth was calculated as a difference of cube roughness before and after immersion.
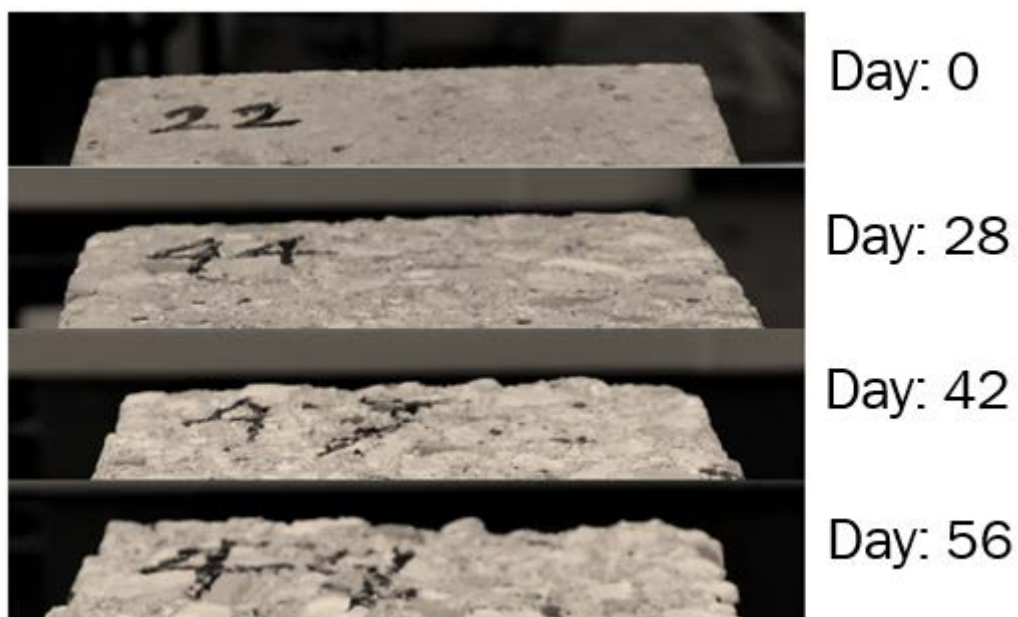

Figure 5. Concrete cubes extracted at different days during the corrosio process.

It should be noted that in these experiments the bottom plane of the cube (as the cube rested on the bottom plane when was inserted into the container with acid solution) was the least affected by the corrosion, however is accounted for in the physical measurements.

2.2 Package A: Results

The results for the mass, corrosion, density and mass loss are presented in the Figures 6-9. In summary: i) At very early stage of the corrosion process concrete mass and density increase; ii) Corrosion establishes quicker in the presence of higher temperature; iii) With time corrosion seems to reach the same level for 20Co & 30Co temperature regimes.
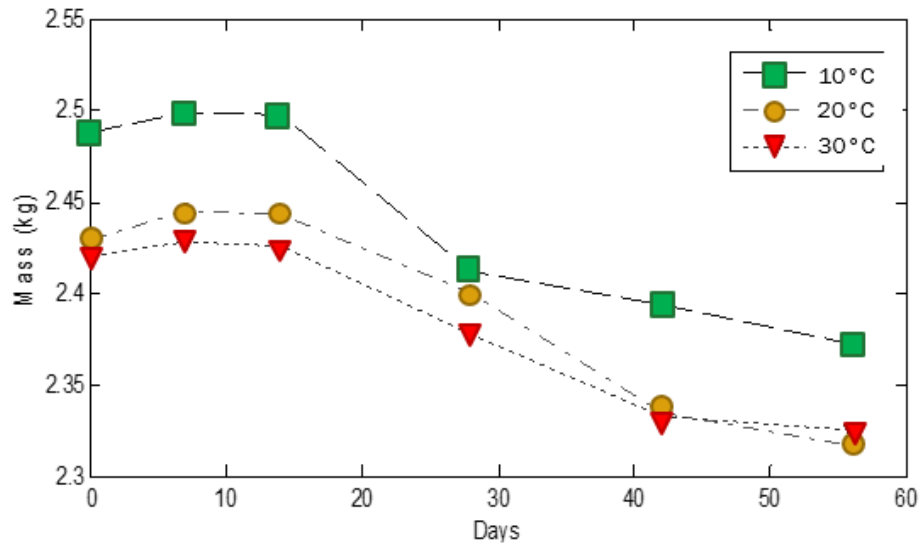
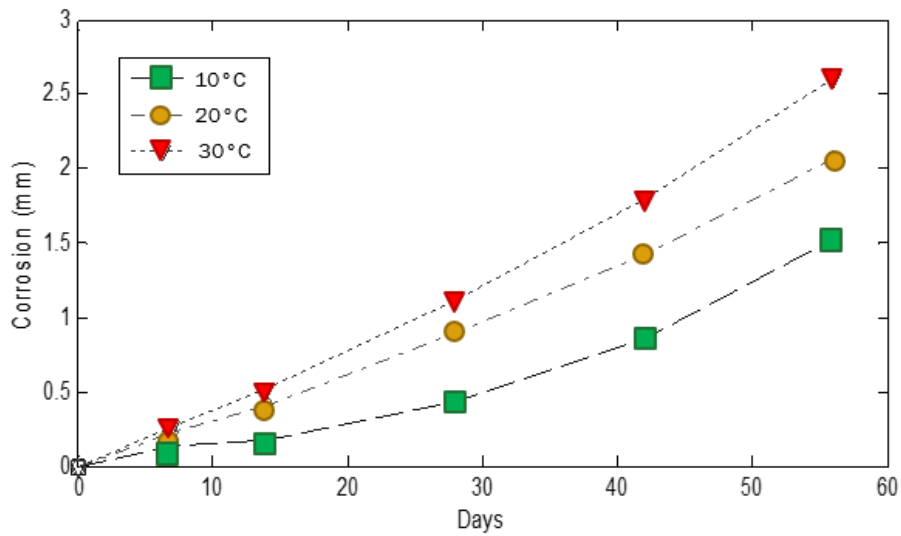Figure 6. Cube mass data for three temperature reghimes recorded for 54 days.

Figure 7. Corrosion rate for three temperature reghimes recorded for 54 days. At these conditions the corrosion rates of 10 mm/year @10ºC, 13,5 mm/year @20ºC and 17 mm/year @30ºC were observed.
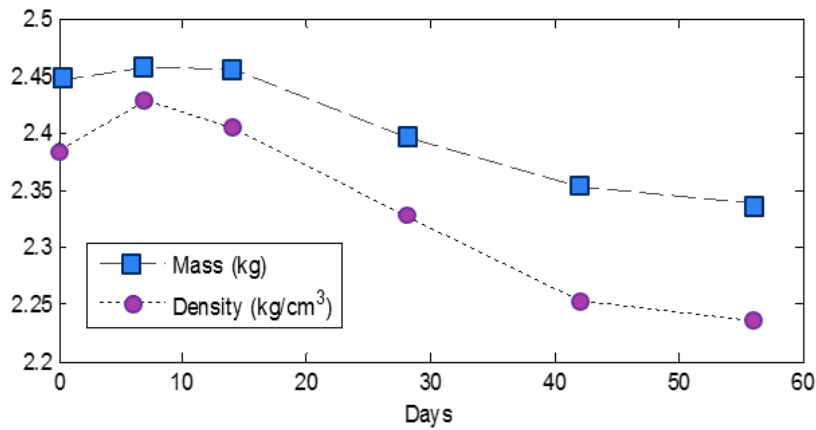

Figure 8. Cube mass and density data averaged for three temperature reghimes recorded for 54 days.
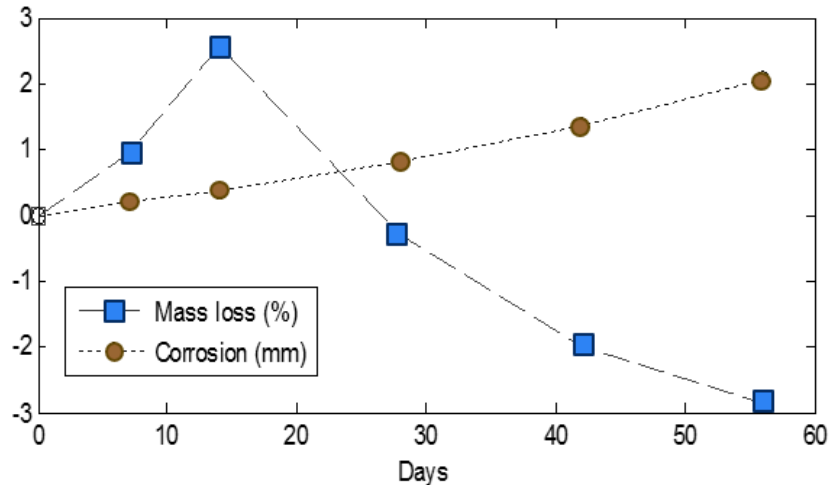
Figure 9. Cube mass loss and corrosion data averaged for three temperature reghimes recorded for 54 days.

2.3 Package B: Set-up

Experiments were conducted in a fully controlled environmental chamber located in Engineering Laboratory at the University of Greenwich.

The chamber hosted three curing tanks with further smaller submerged by 2/3 into the fluid create a thermal bath type effect and control a constant temperature of the 0.8pH and 1.5pH sulphuric acid solution. Four tanks maintained a constant temperature of solution located in containers of 15°C (0.8pH), 25°C (0.8pH), 15°C (1.5pH) and 25°C (1.5pH).

A total number of 168 cubes, cut out from brand-new circular concrete pipe were used in these experiments and cured for 120 days. Each cube had a measurement of 50x50x50mm and was cut with diamond-blade rotating saw.

The difference in the process to Package A eliminated the process of cube brushing and solution stirring during the extraction times.

The review of the data is still in progress.

2.4 Package C: Set-up

For the purpose of field trial experiments two manholes with concrete sewer pipes known to suffer from corrosion process were selected in Rochester and Maidstone, Kent area, UK. Manhole No.1 (Manhole 1) was located in

Chattenden residential area 4676m, 2415m and 2037m downstream from three pumping mains with direct T-type injection connection discharging into this manhole. Manhole No.2 (Manhole 2) was located in Mote Park, Maidstone, further away from residential area however in the vicinity of industrial estate and336m away from the discharge manhole, where the pumped main is 2572m away. For both manholes the concrete sewer pipes were of 300mm external diameter and 35mm wall thickness. Man1 and Man2 were located 19.6km apart.

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 CO^2 (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 H_2S and CO^2 were measured in the air phase, 400mm above the effluent inside the manhole chamber.

2.5 Package C: Results

The results reported in this paper are for a 2 months deployment in Feb-Apr, and is shown Figures 10-13. In summary: i) Effluent pH values do not have a direct correlation with H2S concentration, but can be related to effluent temperature with a shift; ii) On average effluent temperature is higher by 3.5°C than the ambient temp and follows air temperature fluctuations; iii) Hourly parameter patterns are individual for each manhole; iv) H2S and CO2 have an identical (1-2h shift) hourly pattern; v)Concentration of hydrogen sulphide was found to peak with the decrease in temperature inside the manhole as well as during times of low wastewater activity and have a 8-10h shift in general pattern.
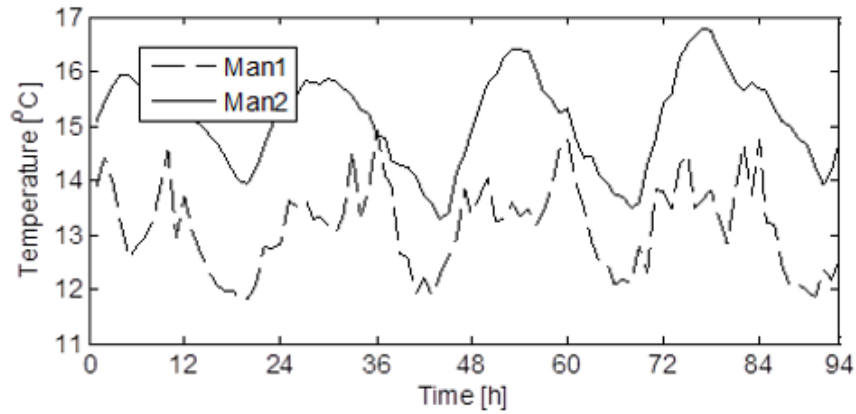
Figure 10. Effluent temperature for Manhole 1 and Manhole 2 for a period of 4 days in the beginning of April shown in hours. Zero set at 10am.
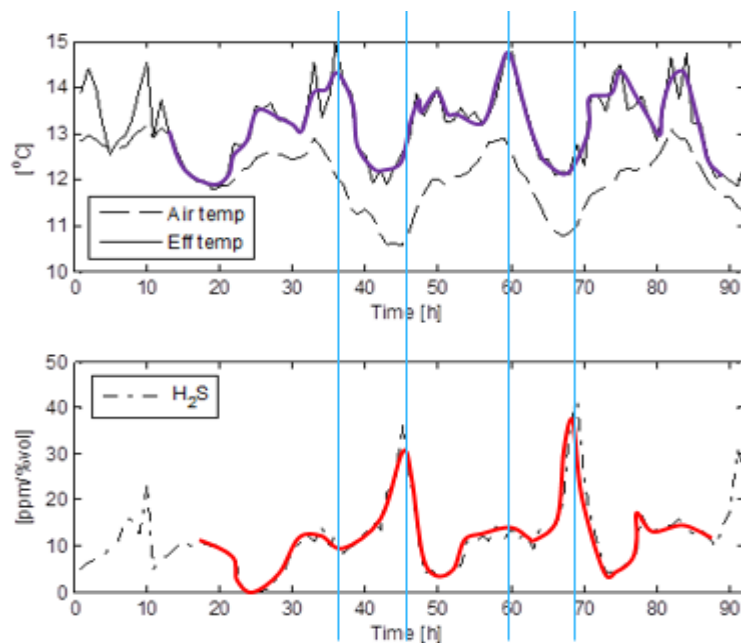

Figure 11. Temperatures and hydrogen sulphide concentration for Manhole 1 for a period of 4 days in April shown in hours. Zero set at 10am. Envelope of each reading collerales with 80% accuracy with 10h shift.
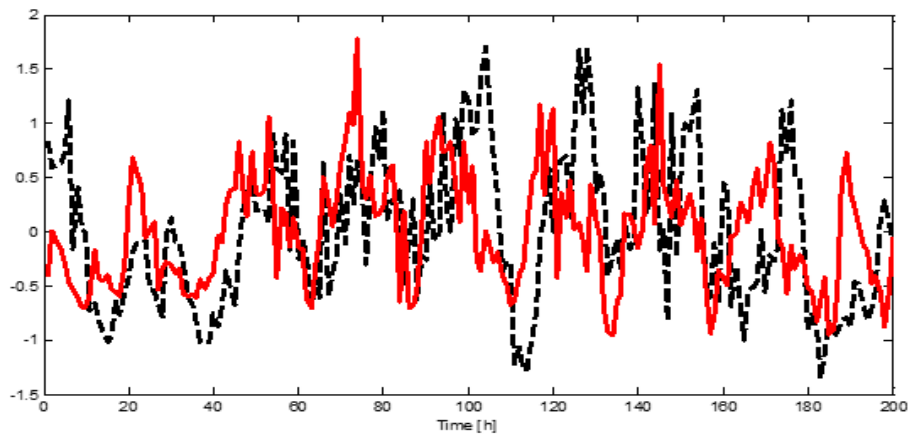

Figure 12. Effluent temperature (black) and pH (red) for Manhole 1 for a period of 8 days in the end of May shown in hours – detrended, resampled & scaled. Zero set at 2pm.
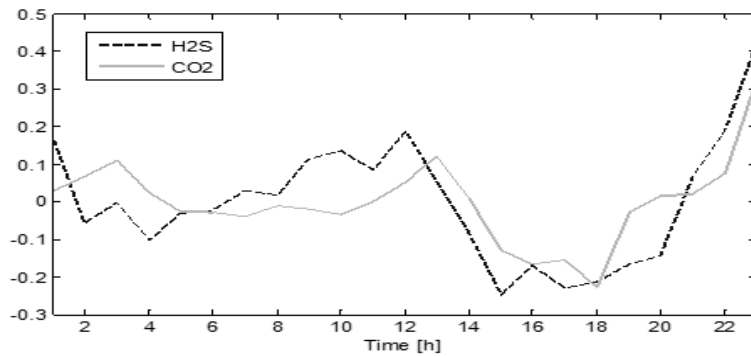
Figure 13. H_2S and CO^2 for Manhole 1 for a period of 23hours in the end of July shown in hours – detrended, resampled & scaled. Zero set at 7am.

2.6 Package D: Set-up

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. Same monitoring equipment at per Package C was used. The data of Austria of comparable manholes was compared to those in the UK in June/July and as can be seen from Figure 14, no H_2S could be detected as the WWTP uses chemicals to remove the characteristic odour associated with H_2S.

PARAMETERS STATISTICAL DATA FOR AUSTRIA

A	Manhole 1				Manhole 2			
	T	pH	H_2S	CO^2	T	pH	H_2S	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

PARAMETERS STATISTICAL DATA FOR UK

UK	Manhole 1				Manhole 2			
	T	pH	H_2S	CO^2	T	pH	H_2S	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

Figure 14. Temperature, pH, H_2S and CO^2 data comparrison for comparative Austria and UK sewers.

2.7 Model

The evolutionary polynomial regression (EPR) method was used to develop a probability of failure model. This method is a data-driven technique which has an ability to process and learn large number of data which do not exhibit linear relation and provide a desirable solution based on input parameters. EPR makes use of a combination of genetic algorithm (GA) and least square (LS) in order to generate a pseudo-polynomial regression model suitable to supplied library of data.

A total number of 142 concrete pipe sections, most with corrosion problem were selected. Pipes were chosen to represent a range of internal diameters (D) of 300mm, 400mm, 500mm, 600mm, 800mm and 1200mm, where the largest population studied were 300mm pipes, totaling to 105 sections. Predominantly the selected pipe sections were installed in 1980's and on the time of survey had an age of 21-29 years (y). Figure 15 shows the range of further parameters, and Figures 16 and 17 demonstrate the EPR equations (C_1 and C_2) with parameter sensitivity.

Parameter	Stats
Total sections	142
Diameters [mm]	300, 400, 500 600, 800, 1200
Installation year	1980's
Age at time of survey	21 - 29 years
Pipe wall thickness [mm]	35 - 65
Slope	0.0003 - 0.09
Water depth [mm]	4.5 - 200
Flow velocity [m/s]	0.36 - 9.12
Effluent temperature [C]	11 - 13
Air temperature [C]	10 - 14
Dissolved sulphite	0 - 5.39
Relative pH	0.03 - 0.2

Figure 15. Selected concrete pipe population physical and chemical parameters.

Figure 16. Generated EPR equations for pipe corrosion with proposed accuracy of 95% and 99%.

Model	D	s	h	b	u	T_s	T_a	DS	j
C_1	10.43	22.61	25.22	17.39	20.87	3.48	-	-	-
C_2	12.48	20.80	22.19	19.42	20.11	1.39	0.35	1.18	2.08

In models C_1 and C_2 the corrosion rate was found to decrease with increasing values of D, u and j.

In model C_1 all parameter weights were rank as h, s, u, b, D, Ts, with first having the most influence.

In model C_2, where the parameters were ranked as h, s, u, b, D, j, Ts, $[DS]$, Ta.

Figure 17. Sensitivity analysis for generated EPR equations for pipe corrosion.

In summary: i) Pipe geometrical parameters and effluent characteristics were collected between 2006-2014 and hence the average annual data was used in EPR. ii) Two EPR models were created, where factors such as h, s, u, b, D, j, Ts, [DS], Ta, were considered. iii) First model had 3 terms and expressed a coefficient of determination of 95%, whereas the second model had 7 terms and suggested an accuracy of 99%. iv) Parameters as h, s, u, b, D and Ts had a great influence on the model. v) Parameters as j, [DS] and Ta had very small influence on the model.

3 References

1. **Romanova, A**., Mahmoodian, M., Chandrasekara, U., Alani, M.A. (2015) 'Concrete sewer pipe corrosion induced by sulphuric acid environment', Int. J. of Civil, Env. and Structural Engineering, 9(4), pp. 450-453.
2. **Romanova, A**., Alani, M.A. (2015) 'Monitoring CO2 and H2S emission in live Austrian and UK concrete sewer pipes', Int. J. of Civil, Environmental and Structural Engineering, 9(4), pp. 420-424.
3. **Romanova, A**., Faramarzi, A., Mahmoodian, M., Alani. M.A. (2014) 'An EPR model for prediction of H2S induced corrosion in concrete sewer pipes', HIC 2014, 17 - 21 August 2014, New York, USA.
4. **Romanova, A**., Mahmoodian, M., Alani. M.A. (2014) 'Influence and Interaction of Temperature, H2S and pH on Concrete Sewer Pipe Corrosion', ICCEIE 2014: International Conference on Civil, Environmental and Infrastructure Engineering to be held in Copenhagen, Denmark, Jun 12-13.
5. Alani. M.A., Mahmoodian, M., **Romanova, A**. and Faramarzi, A. (2014) 'Advanced numerical and analytical methods for assessing concrete sewers and their remaining service life', ICACE 2014: International Conference on Advances in Civil Engineering, Jun 19-20, Venice, Italy.