SP2 Report on

Field Service Models of Polymeric Coatings Based on Acid Resistance

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Summary

Site specific and general models have been developed for polymeric coating to predict their service life in the sewer. The models are based on the rate of acid permeation derived by solving Fick's second law assuming a time dependent surface concentration and time dependent acid diffusion. It was further assumed that the surface concentration of the acid could be described by surface pH or the concentration of H^+ and the nature of the acids that contributes to these values were not considered. The acid permeation was measured from coupon installed primarily in the Sydney Water sewers, North and South Barrel over 30 month period. The reason for choosing this site for this report is the current existence of Sikagard 63N/Sikadur 41 in SWC sewer. Cores on these coatings obtained from these sewers were used to provide the necessary validation for the model developed in this study.

Data obtained from the crown of the South Barrel adequately provided suitable prediction that matches core permeation of the same coating that has been installed in the NGRS and NSOOS sewers for periods of 8 to 14 years. Predictions over these periods were within 3-15% of the observed permeation through the coating (see Table 3).

However data obtained from the crown of the North Barrel sewer under-predicted the core permeation from NGRS and NSOOS sewers. This suggests the corrosivity in the South Barrel provides a more adequate test bed to model the SWC sites than the North Barrel.

Data obtained from the tidal zone also under-predicts the acid permeation of coatings obtained in the wall. This is consistent with the variability in the corrosivity around the sewer, where the highest corrosivity would be found in the crown and the lowest in the tidal and the wall would be in between the corrosivity of the crown and tidal.

Further modelling was also undertaken to take into account the effect of the environmental conditions on the acid permeation. The models were able to adequately predict permeation over periods up to 10 years, but longer service life generated greater discrepancy between the prediction and measured permeation. This could be attributed to the variability in the conditions experienced by the coating over longer periods. For the validation conducted using cores obtained from NGRS and NSOOS, it was assumed the cores experienced similar conditions to that obtained from the North and South Barrels.

1.0 Introduction

To accurately predict the service life of protective polymeric coatings exposed to the corrosive conditions in sewer, it is necessary to estimate the diffusion coefficient of the corrosive reagents. Corrosion and degradation of polymeric coating in sewers has been attributed to organism metabolites including biogenic acids. Because of the continued activity of organisms on the surface of the coating and the viscoelastic properties of polymers, both the surface concentration and diffusivity will vary with time. In this study, the surface concentration of the acid and diffusivity were estimated experimentally by installing coupons of polymeric coatings in the sewer for approximately 3 years. The correlations of these properties with time were determined by taking installed coupons from the sewer at

various intermittent time. The obtained correlations were fitted to Fick's second law to establish a model for predicting the depth of acid permeation with time.

The study of diffusion of biogenic acids through epoxy coatings installed in sewers is complicated by various factors. First the acids are generated biologically requiring the inoculation of the coating surface followed by growth and eventual metabolism of the acids on the coating surface. If conditions that promote biological growth is maintained in the sewer, it would be presumed that the acid production would eventually reach a steady state. Unfortunately fluctuations in the sewer level and effects washing of the surface and the variation in temperature, air flow and variation in waste influx and microflora can contribute to changes in the acid production.

An additional complication in assessing the diffusion through polymers is related to its viscoelastic behaviour. At the beginning of acid transport, most polymer exhibit a glassy behaviour characterised by slow diffusion (see Figure 1).
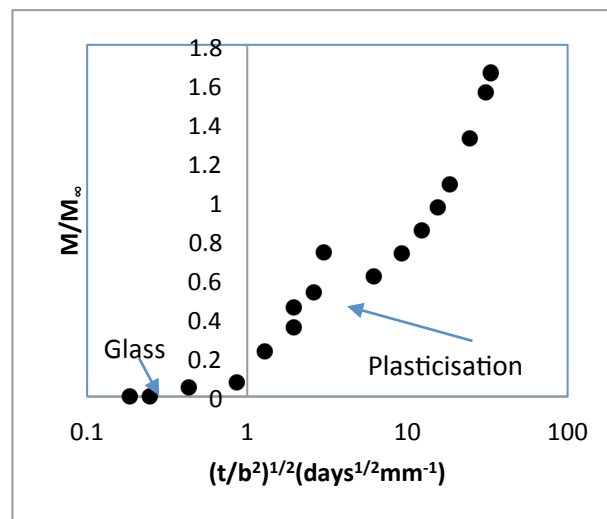

Figure 1. Viscoelastic behaviour of polymeric coatings under acid permeation.

As the acid and/or moisture penetrate, the polymer may undergo plasticisation characterised by swelling by faster diffusion of acids. The crystallinity of the polymer may also contribute to the variation in diffusion. Polar groups are thought to concentrate in the crystalline phase and these are responsible for adsorbing acids on the polymer matrix, inhibiting the transport of the acids.

This study was conducted to establish a method for estimating the service life of coatings in the sewer. The service life was estimated based on models that predict the time for the acid to breakthrough the coating. The model is based on an analysis of the acid production on the coating surface and rate of acid permeation through the coating in field studies.

2.0 Fick's Theory

Prediction of service life of polymeric coatings in sewers is dependent on accurate estimation of the resistance of coatings to the diffusion of biogenic acids. In this study, this was based on the application of the estimated diffusion coefficient and Fick's 2nd law to predict the ingress of acids with time and the time needed for the concentration at the depth interfacing between the coating and concrete to reach the critical threshold value necessary for concrete corrosion to begin.

It has been recognised that the surface concentration and the diffusion will vary with time at the initial phase of service. The unsteady state diffusion of acids can be described by the Fick's 2nd law of diffusion:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \tag{1}$$

which relates the temporal variation of acid concentration, c, to the local spatial variation by the diffusion coefficient, D. In the case of a plane sheet with a uniform initial concentration distribution, constant diffusion coefficient and a constant concentration on the boundary with the following initial condition:

$$c = c_o = 0, \qquad x > 0, \qquad t = 0 \tag{2}$$

and boundary condition:

$$c = c_s, \qquad x = 0, \qquad t > 0 \tag{3}$$

c_0 is the initial acid concentrations, and c_s is the concentration on the surface of the coating, the following solution to equation (1) applies (Crank, 1975):

$$\frac{M_t}{M_\infty} = \frac{c - c_o}{c_\infty - c_0} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} e^{\left(-\frac{D(2n+1)^2 \pi^2 t}{4 l^2}\right)} \tag{4}$$

M_t is the amount of diffusing acid that has entered the sheet, M_∞ is the equilibrium sorption attained after an infinite time and c_∞ is the corresponding equilibrium acid concentration.

The acid content, c, as a function of position ,x, in a semi infinite medium is given as:

$$c = c_s erfc(\frac{x}{2\sqrt{Dt}}) \tag{5}$$

Crank has presented solutions for Fick's 2nd law in the special case when concentration varies with time:

i) c_s = kt, where k is a constant

$$c = 4kti^2 erfc(\frac{x}{2\sqrt{Dt}})$$
(6)

ii) c_s = kt$^{1/2}$, where k is a constant

$$c = k(\pi t)^2 ierfc(\frac{x}{2\sqrt{Dt}})$$
(7)

iii) c_s = kt$^{1/2n}$, where k is a constant

$$c = k\Gamma\left(\frac{1}{2}n + 1\right)(4t)^{\frac{1}{2}n}i^n erfc(\frac{x}{2\sqrt{Dt}})$$
(8)

These solutions could also be used when the diffusion coefficient varies only with time. In this case, the term for D in equations 6 to 8, is replaced by function of diffusion with time, D(t).

3.0 Experimental

3.1 Polymeric Coupon Samples
Six commercially available polymeric based coatings were tested in this study. These were selected by the water utility industries because these have been used in their sewers and have demonstrated reasonable performance or are considered future coatings of interest. The coatings were prepared according to the manufacturer's instruction or have been prepared by the manufacturers. The coupon dimensions installed in the sewer are shown in Table 1.

3.2 Field Installation of Coupons
Coupons were installed in the sewer using SS steel baskets with a PVC lid (see Figure 2). The coupons were secured using plastic cable ties. The baskets were placed on the crown and on the tidal zones of the sewer and secured there with bolts (see Figure 3).

3.3 Installation and Retrieval Schedule

Coupons were installed in two sewer locations in each of the three cities, Sydney, Melbourne and Perth. The coupons were installed for a total of 30 months and were extracted at approximately every 6 months. The installation and retrieval schedule is summarized in Table 2.

Table 1. Coatings used in field tests.

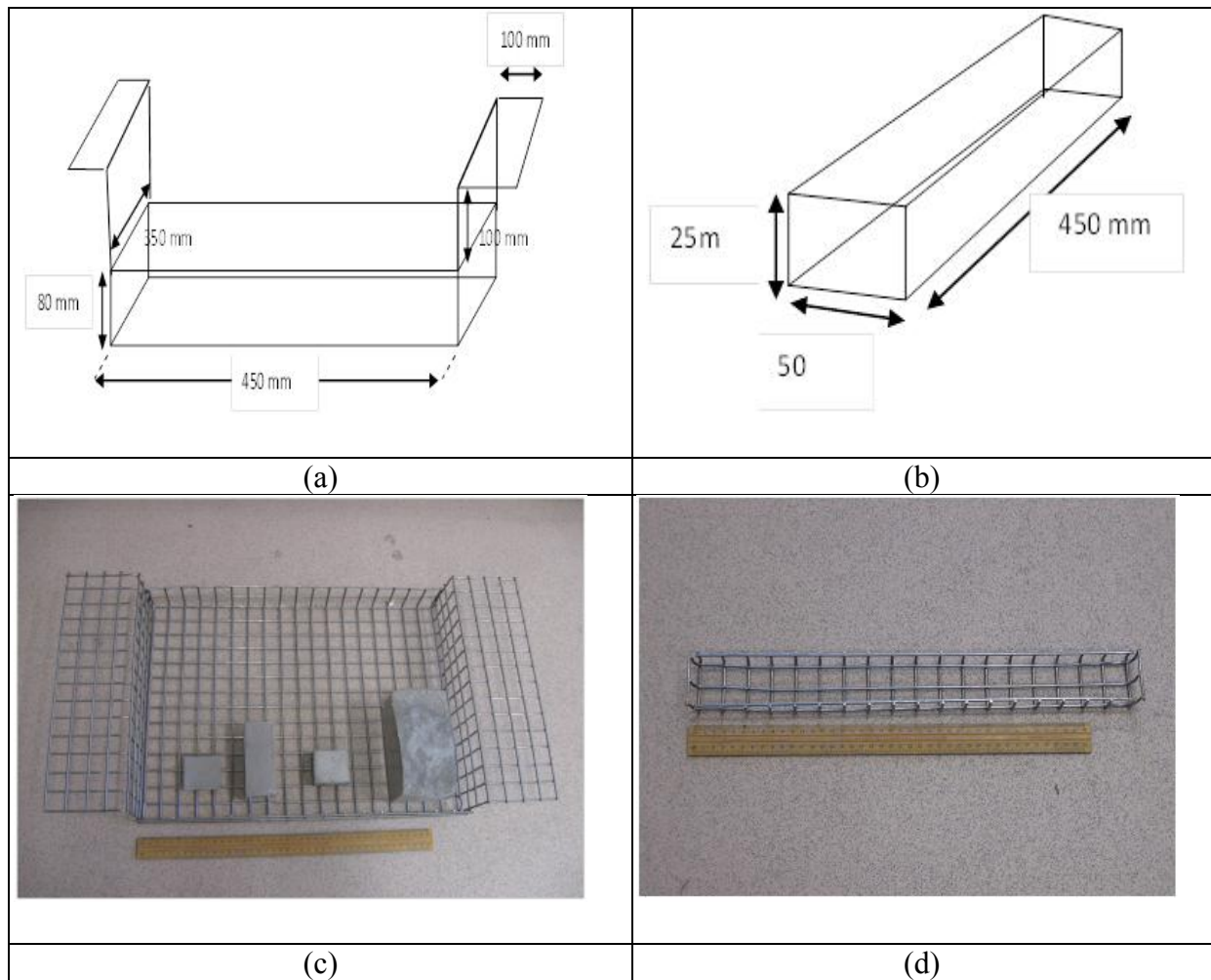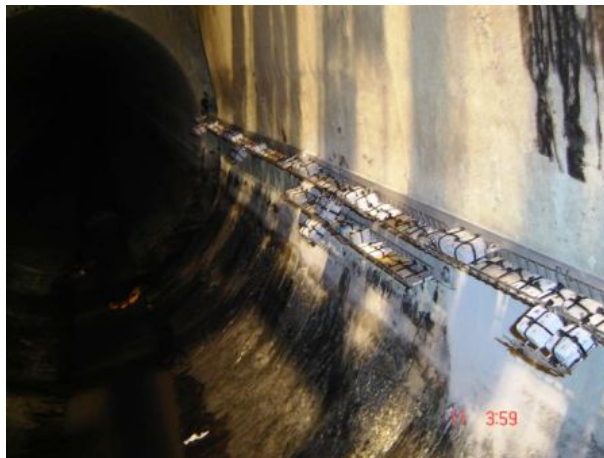| Nature of Coatings	Coatings	Manufacturer	Dimensions
Coupons of *Epoxy and polyurea* coatings only	Sikadur 41	Sika Pty. Ltd.	50mmx50mmx10mm
	Sikagard 63N	Sika Pty. Ltd.	50mmx50mmx10mm
	Hychem TL5		50mmx50mmx5mm
	Nitomortar ELS	Pharchem	50mmx50mmx10mm
	Polibrid 705E		50mmx50mmx5mm
	Fernco S301		50mmx50mmx10mm

Figure 2. Field Installation Baskets

Crown

Tidal Zone

Figure 3. Installation of coupons in the crown and tidal zones of sewers.

Table 2. Installation Schedule

City	Sewer Location		Installation dates	Retrieval Dates				
	High H$_2$S	Low H$_2$S						
Sydney	SWOOS South Barrel	SWSOOS North Barrel	22/09/2009	17/6/2010	21/9/2010	29/3/2011	19/9/2011	3/4/2012
	Period of Installation, days			**268**	**364**	**553**	**727**	**924**
Melbourne	WTS	SETS	5/2/2010	24/9/2010	22/2/2011	22/8/2011	20/2/2012	
	Period of Installation, days			**231**	**382**	**563**	**745**	
Perth	Bibra Lake	Perth MS	6/5/2010	7/12/2010	28/6/2011	6/12/2011	3/7/2012	
	Period of Installation, days			**215**	**418**	**579**	**789**	

3.4 Core Samples of Coatings in Service

To validate the acid permeation over long term service, cores of coatings th[...]
service for 3 to 14 years have been sampled (see Figure 4). A total of 20 core[...]
from sewage pipes around Sydney, 4 at each location, 2 from upper wall and 2[...]
walls of the sewer pipes. A list of the cores obtained is shown in Table 3.

Figure 4. Cores of polymeric coatings and concrete susbtrates from SWC sewe[...]

3.4.1 Pharchem ELS Coating

The Pharchem ELS samples were obtained from two locations, SWOOS2 [...]
Banksmeadow -- ELS Section (3 years old) and NGRS - Renown Park, Oatley[...]

3.4.2 Sikadur 41 + Sikagard 63N

The Sikadur 41 and Sikagard 63N coating samples were taken from three si[...]
West St, South Hurstville, applied in 2002 (the samples were 8 years only[...]
analysis in 2010), (2) Herbert St, NSOOS West Ryde applied in 1998 (the s[...]
years old on the time of analysis in 2008) and (3) Market Lane, NSOOS, app[...]
years on the time of analysis in 2010).

3.4.3 Concressive 1446/1405

Concressive 1405 was not a coating included in the list to be tested under th[...]
SWC has supplied these coating cores for analysis in addition to the other cor[...]
coatings were taken from Eve St location in the SWOOS. This was applied in[...]

Table 3. Core sampling of Epoxy coatings location

Core	Location Address	Date of Core Retrieval	Location	Type of Coating	Supplier	Coating Installation	Age of Coating (years)	Nomimal Thickness mm	Hard-ness	pH roof	pH wall	H_2S, ppm
1	NGRS - West St, South Hurstville	11.02.2010	Upper Wall North	Sikadur 41/63N	Sika	2002	8	20	68	0-1	2-3	10
2			Lower Wall North									
3			Upper Wall South									
4			Lower Wall South									
5	SWOOS2 - Botany Road, Banksmeadow -- ELS Section	12.02.2010	Upper Wall North	Nitomortar ELS	Pharchem	2007	3	20	60	4-5	0-1	5-10
6			Upper Wall North									
7			Lower Wall North									
8			Lower Wall North									
9	NGRS - Renown Park, Oatley	10.02.2010	Lower Wall North	Nitomortar ELS	Pharchem	2004	6	20	63	0-1		5-10
10			Lower Wall South									
11			Upper Wall North									
12			Upper Wall North									
13	NGRS, SWOOS, Eve St. Merging Chamber	02.02.2010	Lower Wall	Concresive 1405 as the coating to seal	MBT Australia now BASF	2002	8	20	68	NA	3-5	5-20
14			Lower Wall									
15			Upper Wall									
16			Upper Wall									
17	Market Lane, NSOOS	02.02.2010	Upper Wall	Sikadur 41/63N	Sika	1996	14	20	NA	NA	NA	NA
18			Lower Wall									
19			Upper Wall									
20			Lower Wall									

3.5 Coupon Surface pH

Coupons retrieved from the sewers were wiped with paper towel to remove an
materials. This were sterilised using ultraviolet light at room temperature for 3(
The surface is sprayed with water and the surface pH is measured with a
conductivity-salinity-pH-temperature surface probe. The surface pH test was
various parts of the coupons and an average was determined for at least 3 reading

3.6 Rate of Permeation

Coupons are sliced across the length with a diamond saw to expose their e
Universal indicator was sprayed on the cross-sectional area to reveal the acidity
acid permeation through the coating. The extent of permeation was measured vis
Leica Microscope DM2500 using 2.5 x magnification. The depth of peri
measured using Leica Application Suite V3.

4.0 Results

4.1 Surface Acid Concentration of Coupons in Sewers (Cs)

The acid content (c) as a function of position (x) was given in equation 5:

$$c = c_S erfc(\frac{x}{2\sqrt{Dt}})$$

Surface concentrations of acids (c_s) that may be present on the coupon :
determined using surface pH. Here it was assumed the corrosion occurs primari
of the coating attack by the H^+ ions and that corrosion could be related directly t
(H_3O^+) ion concentration. The surface concentration will decrease as a function
result of biological activity on the surface of coatings. The aim of this part of th
develop models that describe the surface neutralisation or the reduction of pH
with time.

An example of the variation of the surface pH of Sikadur 41 coated with 150 μn
63N in Sydney Water sewers over time is shown in Figure 5. As shown, the pH
crown is relatively higher compared to the tidal zone suggesting the higher corr
crown. It also appears the corrosivity in the North barrel is higher compared
barrel despite having relatively similar H_2S gas concentration. Again this w
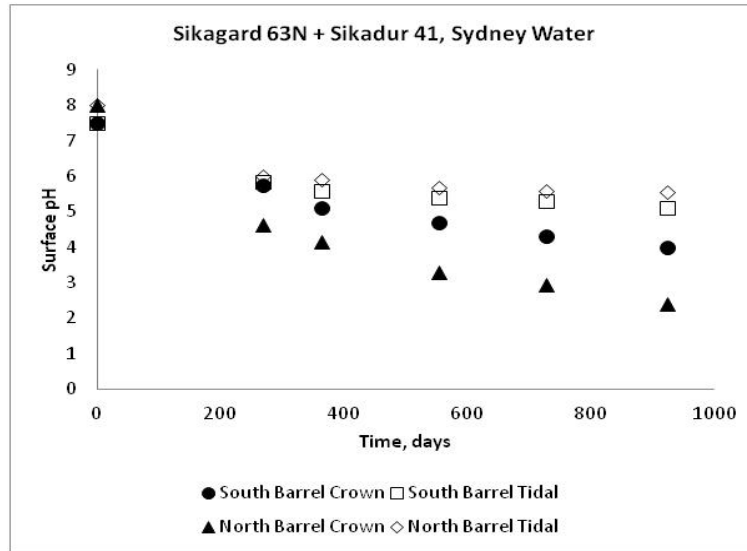greater microbiological activity in this site.

Figure 5. Surface pH variation of Sikadur 41+Sikagard 63N installed in the crown and tidal zones of the SWSOOS North and South barrels of Sydney Water.

4.2 Surface Acid Concentration Model at Short Installation Periods (< 3 years)

The dependency of surface concentration, $C_{H_S^+}$ with time was established by fitting the data though various functions. The best fit over the time period ($\sim$ 980 days) of the test was obtained using a power law function:

$$C_{H_S^+} = \frac{1}{C_o} t^\beta \qquad (9)$$

where $pH = -\log(C_{H_S^+})$, Co and β are both constants and t, the period of installation is measured in seconds. The constants were determined by linearising equation (9) and plotting pH as a function of log (t) to give a slope of $-\beta$ and an intercept of $-\log(C_o)$. A plot of surface pH of Sikagard 63N/Sikadur 41 that were installed in the North and South barrels in Sydney are shown in Figure 6. A summary of the constant parameters derived from the plot and regression correlation R^2 between the experimental pH and predicted are shown in Table 4. The values of R^2 were mostly above 0.9, which suggests the power model adequately describes the acid neutralisation with time.
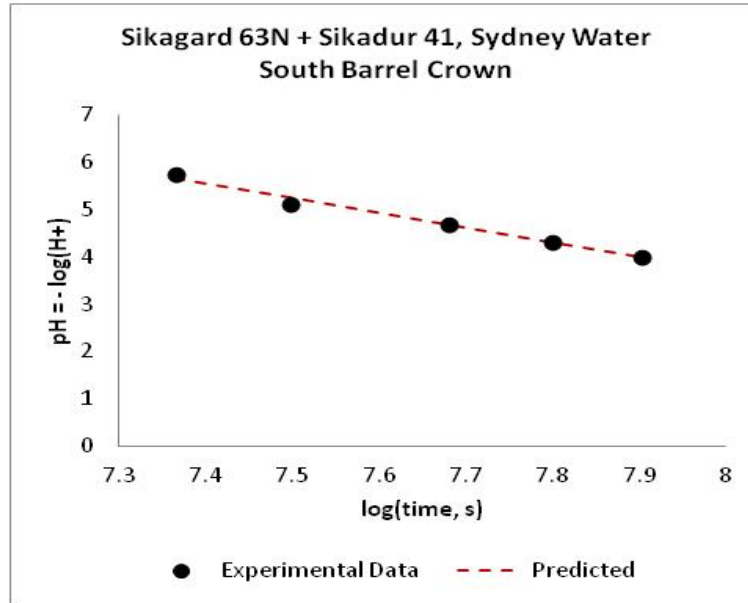
Figure 6. Surface concentration of Sikadur 41/Sikagard 63N with time installed in the crown of Sydney South Barrel sewer and predicted surface concentration according to equation 9.

Table 4. Constant Parameters for Surface Profile of Sikadur 41/Sikagard in Sydney Water Sewers over short installation period based on equation 9.

Sewer Location	C_o (s/mol.l^{-1})	β	R^2
South Barrel, Crown	1.64×10^{45}	5.4	0.91
South Barrel, Tidal	3.45×10^{14}	1.2	0.92
North Barrel, Crown	1.6×10^{59}	7.3	0.95
North Barrel, Tidal	9.8×10^{21}	2.1	0.72

4.3 Surface Acid Concentration Model Longer Installation Periods (> 3 years)
Over long periods, the pH will approach a constant value as organism approach surface pH to which they are tolerant. Most strains of the *thiobacillus thiooxidan* will reach pH of about 0.8- 1.0, whilst pH as low as 0.2 has been observed possible (Lee et al., 2006). The concentration and time profile with the tail end of the change in surface pH over longer periods of installation was found to follow the following function:

$$C_{H_S^+} = 10^{alog(\mathrm{erf}(b.t))} \qquad (10)$$

where a and b are constants and the time t is given in days. An example of the concentration profile of a coating, Sikagard 63N/ Sikadur 41, and the fitted function is shown in Figure 7. The function, as shown, closely describes the surface pH data with regressional coefficient of

0.95. A list of constant parameters derived for Sikadur 41 installed in Sydney Water sewers over longer periods are shown in Table 5.
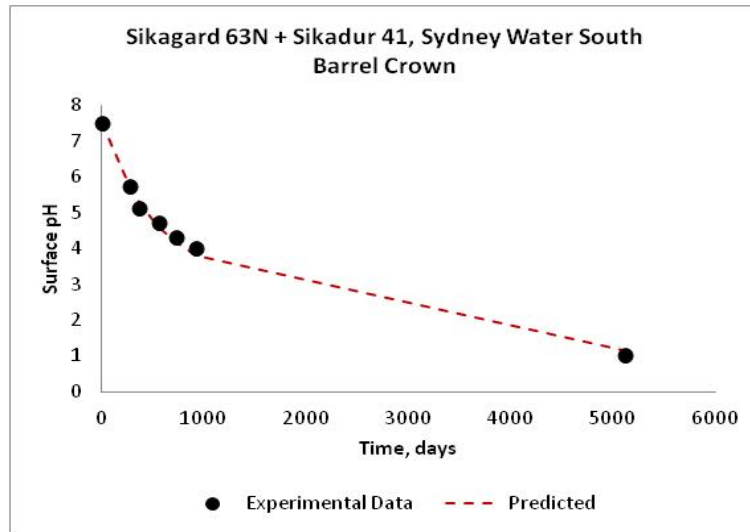

Figure 7. Surface pH of Sikadur 41/Sikagard 63 with time installed in the crown of Sydney South Barrel sewer over a long period of time and predicted surface concentration according to equation 10.

Table 5. Constant Parameters for Surface Profile of Sikadur 41 in Sydney Water Sewers over long installation periods based on equation 10.

Sewer Location	a	b
South Barrel, Crown	4.8	2.5x10-4
South Barrel, Tidal	3.0	$2.7x10^{-5}$
North Barrel, Crown	7.6	$6.1x10^{-4}$
North Barrel, Tidal	4.1	$6.8x01^{-4}$

4.4 Acid Diffusion and Service Model at Short Periods

The diffusion coefficients of biogenic acids with time were modelled by examining the acid permeation of coupons that were installed at various periods of time. An example of average depths of acid permeation is shown in Figure 8. These are the acid permeation of Sikagard 63N/Sikadur 41 that were installed in Sydney Water sewers for 30 months. As shown the permeation is characterised by two stages, a lag phase and a rapid phase. From 0 to 230 days, the rate of acid permeation was slow, and it is considered that here the polymer behaved in a glassy phase. The second phase, after 230 days, characterised by a rapid increase in acid permeation reflect the acid attack of the polymer network resulting in polymer plasticisation.

The relative rate of acid permeation also reflects the corrosivity of the sites. As shown the relative rate of acid permeation in the crown is higher compared to the tidal zone, which is consistent with the lower pH observed at the crown. The higher acid permeation in the crown South barrel site in comparison to the North barrel site does not appear to be related to the surface pH developed at these sites.
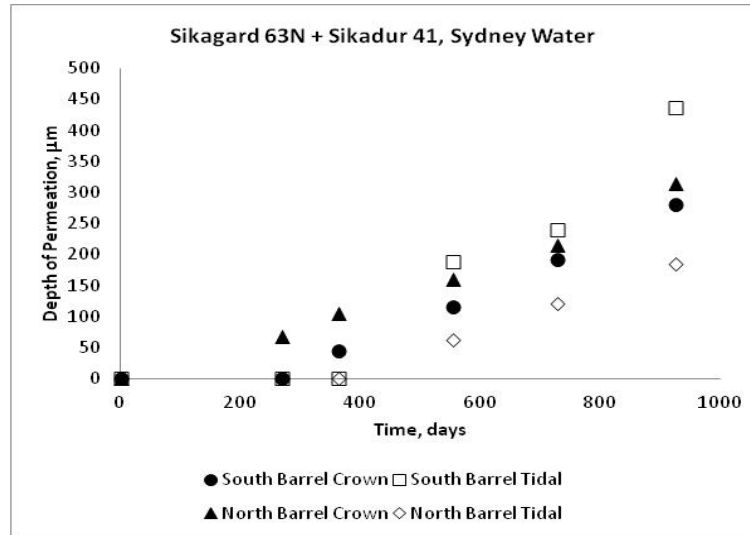

Figure 8. Average Depth of Acid Permeation in Sikadur 41/Sikagard 63N installed in Sydney Water Sewers

It was assumed that for the coating tested over the short period of installation (30 months) , the power function given in equation (9) adequately describes the correlation of surface pH with time (see Figure 6). Crank (Crank, 1975) has given equation (8) as the solution for Fick's 2nd law for the special case when surface acid concentration varies with time according to the power law function. Incorporating the constants of equation 9 (k = 1/C_o; n/2 =β) to equation 8 gives:

$$c = 1/C_o \Gamma(\beta + 1)(4t)^\beta i^{2\beta} erfc(\frac{x}{2\sqrt{Dt}}) \tag{11}$$

The diffusion coefficients of the biogenic acids were determined by fitting the acid permeation data to equation (11).

Due to the viscoeslastic nature of the polymer, the diffusivity of the acids can vary with time. The permeation is typically subjected to two phases as suggested above, the glassy state, characterised by extremely slow or zero diffusion and the plastic stage. At the plastic stage the acid will permeate rapidly. This variation of the diffusion coefficient, D, with time was found to fit a power function:

$$D(t) = D_o t^m \tag{12}$$

where D_o and m are constants. An example of the fit of biogenic acid diffusion coefficients of the biogenic acids Sikagard 63N installed in the crown of SWC South and North Barrels to

the power function is shown in Figure 9. The fits for the South Barrel and North Barrel gave R^2 of 0.98 and 0.93 respectively. Both the experimental and diffusion data predicted using equation (12) are superimposed in Figure 9. As shown, the predicted diffusion data corresponds well to the experimental data.

Equation (11) was further modified by incorporating equation (12) to equation (11):

$$c = C_o \Gamma(\beta + 1)(4t)^\beta i^{2\beta} erfc(\frac{x}{2\sqrt{D(t)t}}) \tag{13}$$

Equation (13) provides a suitable solution for Fick's second law that accounts for both the variation in concentration and diffusivity with time over short periods (Crank, 1975, Mangat & Molloy, 1994). Given the permeation data obtained in this study, equations 13 provides an approximate estimate of diffusion coefficient over short periods of installation (~ 980 days) when concentration follows the power law model. The effect of diffusion under the glassy state must be taken into account by correcting the permeation equation with the lag phase (t = t_i - t_{lag}). The time t_{lag} can be estimated experimentally from the acid permeation with time.
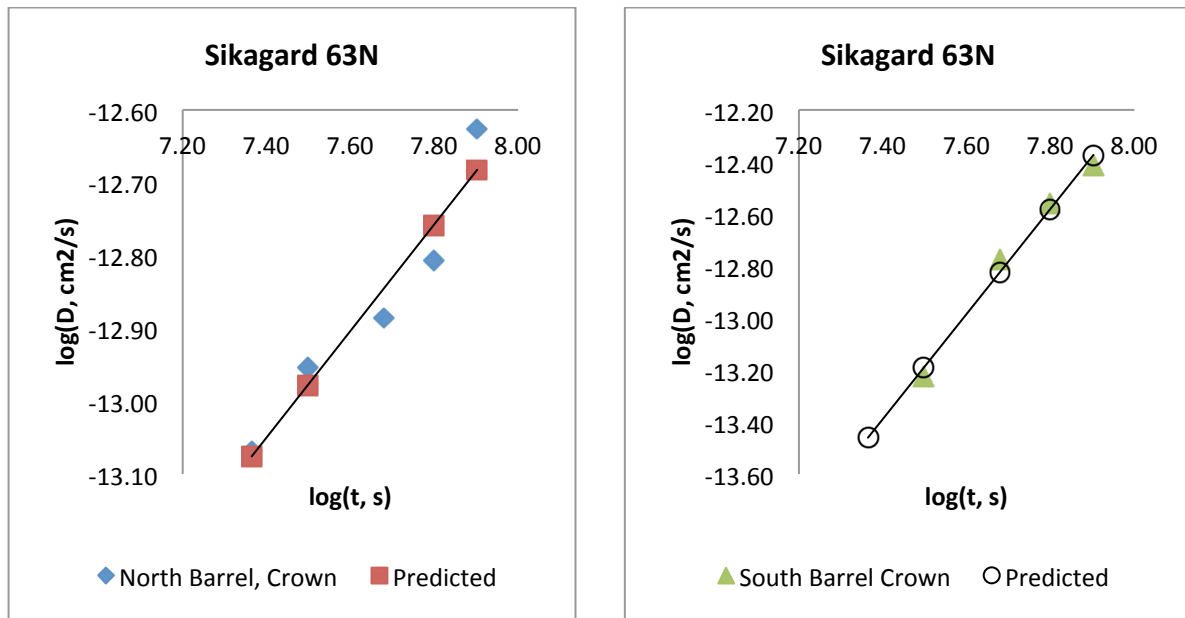

Figure 8. Diffusion coefficient of biogenic acids in Sikadur 41 installed in the SWC South Barrel sewer crown, fitted to a power function.

4.5 Service Life Equation – Longer Periods and Lag Phase

Longer term prediction in reality is what is required to establish the service life of coatings that are expected to last as long as 50 years. The model for this process will need to consider that surface pH will decline and will eventually become constant (see Figure 7). Prediction of surface pH over long periods is best described by equation (10).

When the surface concentration is constant but the diffusion coefficient continues to vary with time, that is $C_{H_S^+}$ = constant and $D(t) = D_o t^m$, the solution to Fick's 2nd law will

revert back to the familiar form of equation (5) (Crank, 1975, Mangat & Molloy, 1994, Takewaka & Mastumoto, 1988):

$$c = C_{H_S^+} erfc\left(\frac{x}{2\sqrt{D(t)t}}\right) \qquad (14)$$

Incorporating the effect of glassy state in lagging the acid permeation gives:

$$c = C_{H_S^+} erfc\left(\frac{x}{2\sqrt{D(t-t_{lag})(t-t_{lag})}}\right) \qquad (15)$$

Equation (15) describes the acid permeation through polymeric coatings over longer periods of time.

4.7 Empirical Correlations of Surface pH and Diffusion Coefficient

The surface pH models (equation 8 and 9) and diffusion model (equation 12) have been developed for each coating. Thus the use of permeation model (e.g., equation 15 for longer service life) would require the parameters for each type of coating.

To simplify the equations, empirical correlations of the surface pH and diffusion coefficients with the physical and chemical properties of the coating and the environmental conditions were developed.

4.7.1 Empirical Surface pH models

The surface pH model was further expanded to take into account the environmental conditions and the properties of the coatings. The data were fitted to the following empirical model:

$$pH_s = -\log\left(C_{H^+{}_s}\right) = k\left(10^{(a\log(\text{erf}(bt)))}\right)[H_2S]^\alpha [T]^\beta [RH]^\gamma [LOI]^\varepsilon [D]^\theta [H]^\rho [F]^\tau \quad (16)$$

where

pH$_s$ = surface pH

k = constant

t = time (days)

H$_2$S = hydrogen sulphide concentration (ppm)

T = environmental temperature (°C)

RH = relative humidity (%)

LOI = loss on ignition ~ polymeric component (%)

D = filler size (μm)

H = hydrophilicity

F = polymer functionality

The fitted parameters for the surface pH models for coupons installed in Sydney, Melbourne and Perth are summarised in Tables 6 and 7. The fit of the model are shown in Figure 9 with the measured R^2 and adjusted R^2. The adjusted R^2 were measured to give an indication of the bias of fitting multiple parameters to the data. A shown the R^2 are from 0.81 to 0.9 and the adjusted R^2 are from 0.8 to 0.89 demonstrating the suitability of the empirical models in describing the effect of coating properties and environmental condition on surface neutralisation of the coatings.

Table 6. Surface pH parameters – environmental conditions

City	k	a	b	α	β	γ
Parameters		t	t	H_2S	T	RH
Sydney	72.9	-0.869	1.00	0.01	-1.66	0.17
Melbourne	45.4	-0.937	51.20	-0.23	-0.64	-1.84
Perth	424.6	-0.416	5.89×10^{-5}	-0.05	0.19	-0.79

Table 7. Surface pH parameters – coating properties

City	ε	θ	ρ	τ
Parameters	LOI	D	H	F
Sydney	0.00	0.26	-0.72	0.36
Melbourne	0.99	0.67	-6.56	-2.40
Perth	-0.40	-0.26	5.91	2.52

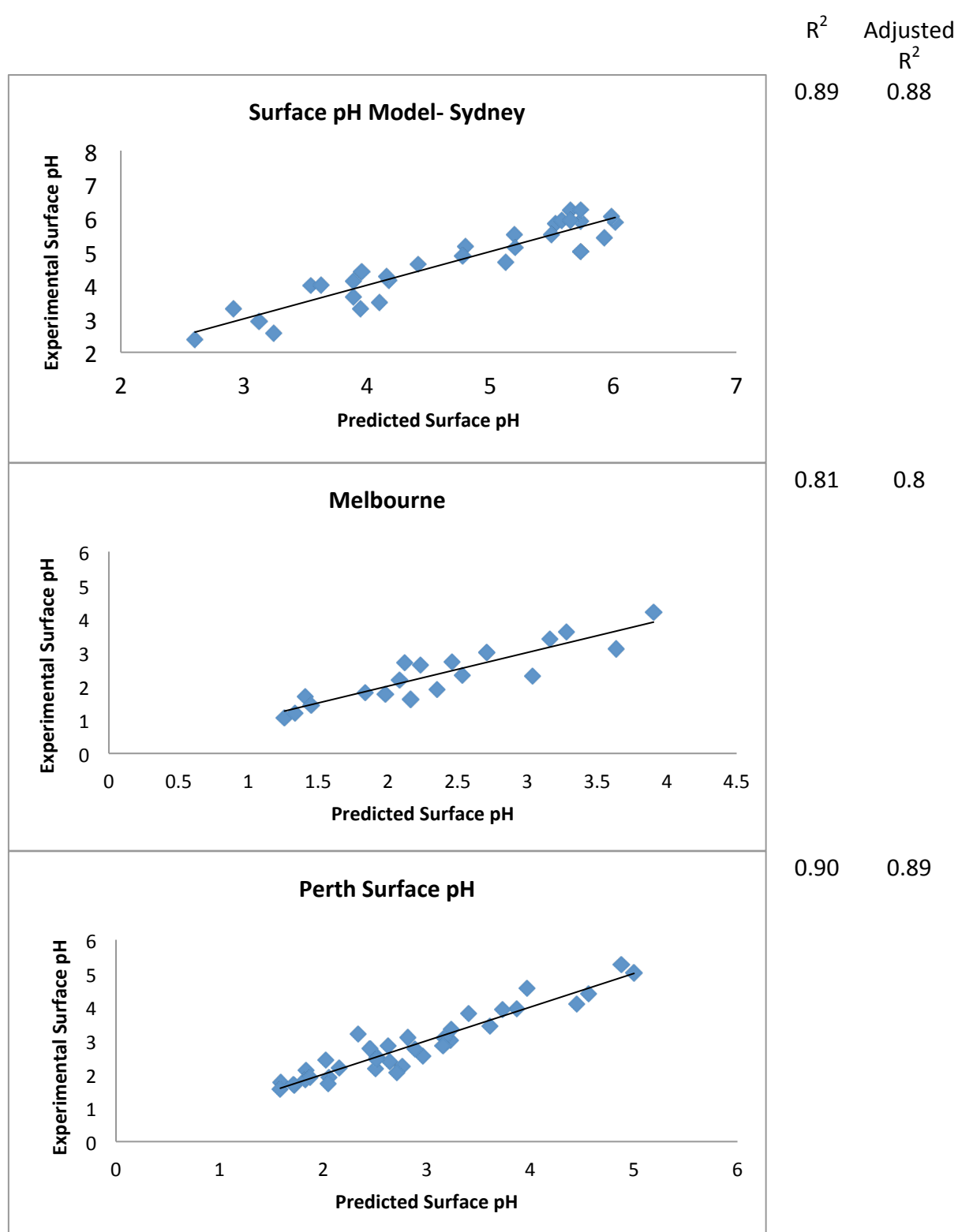|	R^2	Adjusted R^2
Surface pH Model- Sydney	0.89	0.88
Melbourne	0.81	0.8
Perth Surface pH	0.90	0.89

Figure 9. Fitted surface pH models.

4.7.2 Empirical Diffusion pH models

The diffusion coefficients were fitted to the following empirical model to establish its correlation with the environmental conditions and coating properties:

$$\log(D) = k[H_2S]^\alpha [T]^\beta [RH]^\gamma [LOI]^\varepsilon [D]^\theta [H]^\rho [F]^\tau [l]^\varphi [logt]^\omega \qquad (17)$$

Where

l = coating thickeness (mm)

The fitted parameters are shown in Tables 8 and 9. The fit of the models are shown in Figure 10 with the corresponding R^2 and adjusted R^2.

Table 8. Surface pH parameters – environmental conditions

City	k	ω	α	β	γ
Parameters		logt	H₂S	T	RH
Sydney	-10.20	-0.39	-0.03	0.20	-0.02
Melbourne	-9.79	-0.41	-0.02	0.08	0.12
Perth	-9.81	-0.38	-0.04	0.06	-0.15

Table 9. Surface pH parameters – coating properties

City	ε	θ	ρ	τ	φ
Parameters	LOI	D	H	F	l
Sydney	0.04	-0.02	-0.18	-0.10	0.03
Melbourne	-0.02	-0.06	0.62	0.27	0.10
Perth	0.08	-0.02	-0.05	0.93	-0.07

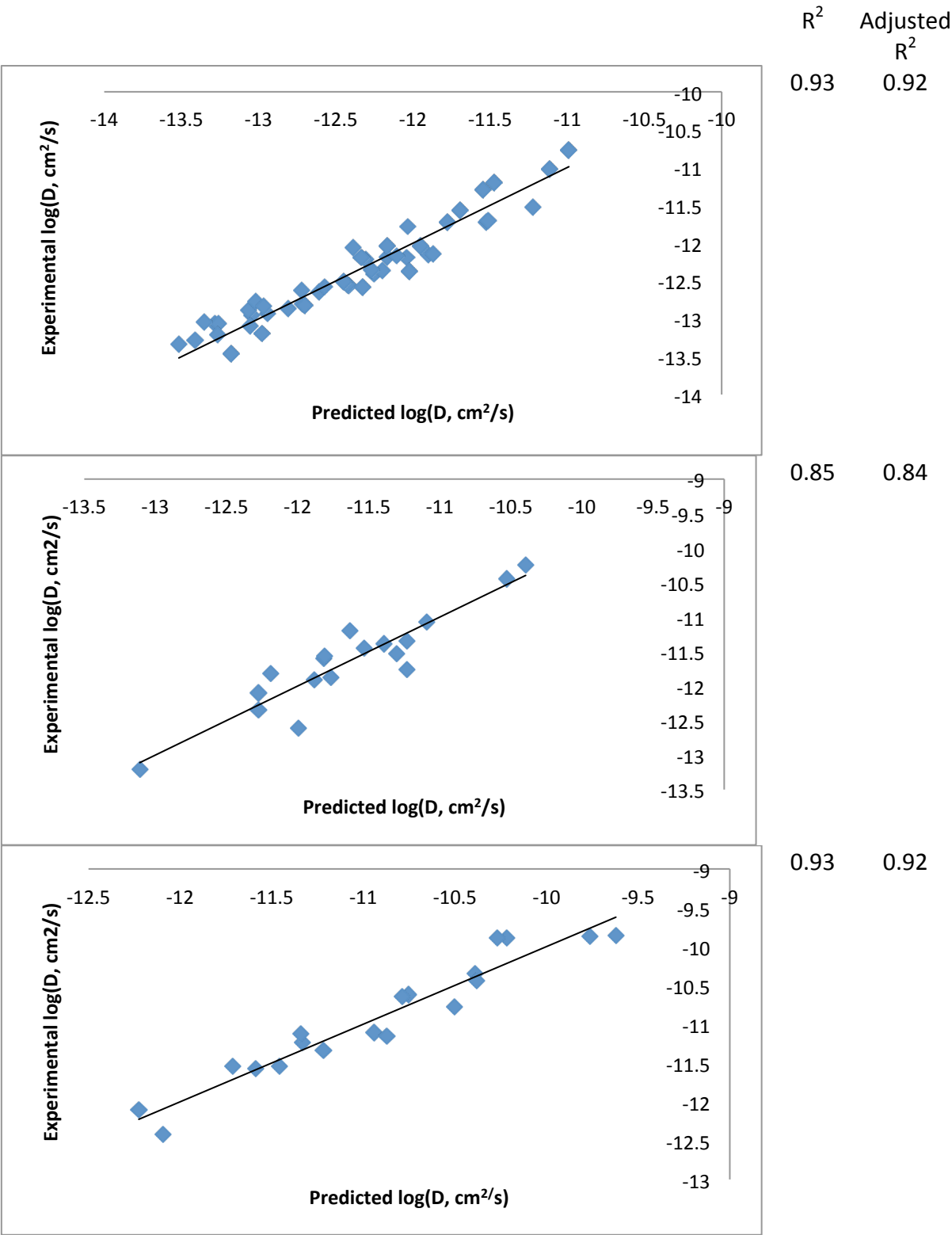|	R^2	Adjusted R^2
	0.93	0.92
	0.85	0.84
	0.93	0.92

Figure 10. Fitted Diffusion models.

4.8 Validation of acid permeation models

Equations 13 and 15 with equations 16 and 17 were employed to estimate the rate of biogenic acid permeation through Sikagard 63N and ELS. These were compared to the observed acid permeation of coupons installed in SWSOOS 2 for 30 months and from cores of similar coatings with field service of 3 to 14 years were obtained from the NGRS, NSOOS and SWSOOS sewers. The results are plotted in Figures 9 and 10. A direct comparison is also made in Table 10.

In both comparisons, acid permeations through coupons installed for 30 months fitted well with the model predictions with 4 to 30% difference. Longer term predictions demonstrated a difference of 8 to 50%. It should be noted that the models were developed for the roof while the cores were obtained from the wall. It is expected that there may be a slight difference in the rate of permeation in both sites.

Table 10. Validation of Site Specific Acid Permeation Modelling of Acid Through Sikagard 63N/Sikadur 41.

Service Period, years	Core permeation, μm	Predicted permeation, μm	% Difference
8	3075	2586	15
10	3875	3316	14
14	6200	5019	19

Based on the current model, the ±20 mm Sikagard 63N/Sikadur 41 coatings should have a service life of 30.8 years. To provide a resistance of 50 years requires 42.3 mm coating.
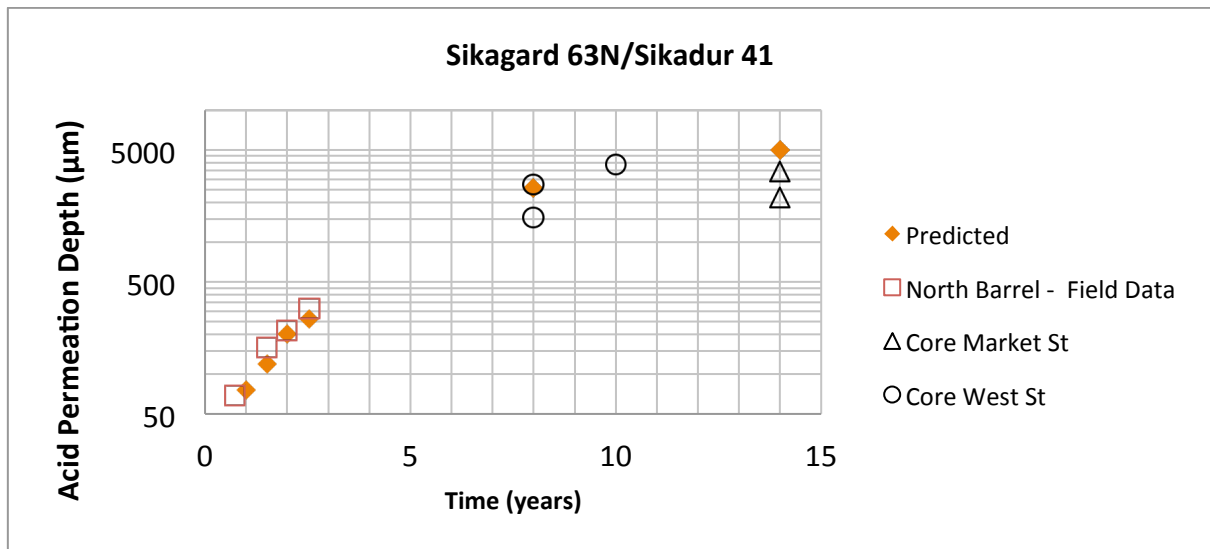
Figure 9. Comparison of predicted permeation depth for Sikadur 41/Sikagard 63N installed in the crown of SWSOOS South and North Barrel and cores of Sikadur 41/ Sikagard 63N from the crown of NGRS and NSOOS sewers.
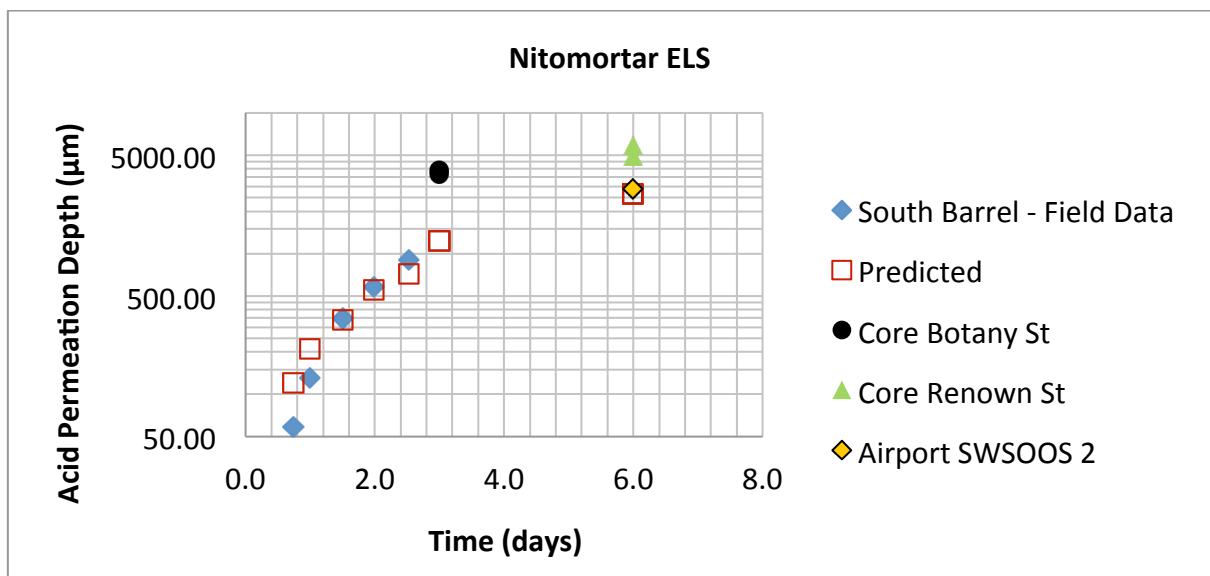

Figure 10. Comparison of predicted permeation depth for ELS installed in the crown of SWSOOS South and North Barrel and cores of ELS from the walls of NGRS, NSOOS and SWSOOS 2 sewers

5.0 References

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