

# KEY PERFORMANCE INDICATORS FOR IMPROVED COATING SELECTION IN WASTEWATER SYSTEM

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## ABSTRACT

When attempting to specify a protective coating for service in water treatments systems, understanding the key performance indicators (KPI) required for a coating to perform well is a great starting point. To do this effectively we need to understand the service exposures a coating is going to see, and then develop a robust understanding of the root cause of that corrosion mechanism. Once we understand the form and effects of the corrosion mechanisms, we can better select a coating technology that suits the exposure. Other factors, such as health and safety, cost, technical support requirements may impact a decision but from an engineering and operations perspective selecting the right coating for the job based on identifying KPI's is the first step.

## 1.0 INTRODUCTION

The American Society of Civil Engineers (ASCE) recently issued their report card on the state of the wastewater infrastructure in the United States, and the marks were not going to make any parent proud. Wastewater was rated at a D+ on a scale of A+ (100%) to F (<60%).

With more than 86% of the anticipated population growth occurring in urban or suburban regions of the USA, the expectation is there will be increased demand on the existing centralized wastewater treatment plants, which collectively process roughly 62.5 billion gallons per day at present. All of this is occurring when most of the nation's WWTPs are designed with an average lifespan of 40 to 50 years. A very telling comment was made in this report, "Across all sizes of the 16000 reporting WWTPs, systems are operating at an average of 81% of their design capacity, while 15% of systems are at, or have exceeded, that threshold"<sup>1</sup>. What this means is the systems that were constructed in the 1970s, around the passing of the Clean Water Act in 1972, are reaching the end of their service lives.

This paper seeks to inform the reader on the primary forms of corrosion and the mechanism of attack commonly seen in water and wastewater treatment plants and to present liquid applied coating technologies as an economically and technically viable option for controlling corrosions impact.

## 2.0 DISCUSSION

To take appropriate corrective actions against the forms of corrosion impacting an item or structure one must first understand how the corrosion mechanisms in play lead to degradation. Relying on my 35+ years in the field of corrosion prevention I have provided pictorial illustrations and descriptions of the primary forms of corrosion impacting wastewater treatment plants and systems.

I focused on corrosion mechanisms most commonly effecting process equipment such as screens, clarifier rake arms, decanters, pumps, valves, mixers as well as structures such as clarifiers, bar screen chambers, thickeners, manholes junction boxes and wet well/lift stations. I then offer up several key performance indicators associated with each form of corrosion which a potential coating selection should meet. It is my hope this paper will provide a useful guide to industry as they down select options for a protective coatings

strategy.

## 2.1 Corrosion of Metals - Pitting Corrosion

Pitting corrosion occurs on carbon steel and cast-iron alloys when the passivated natural oxide ( $\text{Fe}_2\text{O}_3$ ) layer on a metallic surface is disturbed. This results in the exposed region assuming an anodic reaction, while the covered areas remain cathodic. As the anodic region is likely to be far less in surface area than the cathodic region, corrosion “pitting” commences in the anodic region. As corrosion progresses the pit deepens, and the pH levels continue to drop. This causes the anodic/cathodic reaction to continue, albeit at a faster pace. Eventually the pit will exceed the wall thickness of the vessel and leaks and structural failure risks increase.

Stainless steels do not form a layer of oxides like a carbon steel or cast iron but are also prone to pitting corrosion under certain circumstances. In the presence of oxygen or oxygenated water flow, stainless steels containing chromium at a level  $>11\%$ , form a passive layer of chromium oxide. This layer prevents corrosion from occurring. If the surface is covered by biofilms or a gasketed connection or a fabrication detail creates an area of low/no flow, oxygen levels in these regions would be reduced due to little or no flow. These oxygen depleted zones become anodic (lower pH) and corrosion commences.

Pitting corrosion rates on stainless steels can be further exacerbated by chloride levels. These levels can be impacted if using ferric chloride ( $\text{FeCl}_3$ ) as a flocculating agent or to reduce sulfides. Type 304 and 316 stainless are prone to excessive pitting corrosion with chloride levels  $>300$  ppm, even in neutral pH solutions.

Aluminium is a thermodynamically reactive metal, so it is prone to corrosion compared to other more noble metals. Within pH ranges of 4.5-8.5 aluminium is corrosion resistant but, if used in enclosed head spaces in wastewater exposures where hydrogen sulfide gases can build up and result in  $\text{pH} < 4$  pitting corrosion can occur on the aluminium oxide layer as well.



**Figure 2.1 - Pitting corrosion occurring on thickener tank under a biofilm layer**

### KPI's of Coatings Intended for Pitting Corrosion Exposures

- High tensile adhesion ( $>20$  MPa) to resist under film corrosion
- High abrasion resistance to resist losses exposing regions that can become anodic
- Low permeability
- General resistance to thermal, chemical exposures

## 2.2 Corrosion of Metals – Graphitic Corrosion

This form of corrosion is most commonly seen in cast iron and ductile iron when buried in acidic soils or exposed to mildly acidic waters. Under these conditions the iron (Fe) leaches out of the casting into the soil or water flows, leaving behind a weakened matrix of graphite and iron oxides. Casual observation will not indicate any damage, but the remaining matrix of graphite and iron oxides are weak and soft and, if left unaddressed, can lead to collapse or structural failure. This form of corrosion is very slow so many systems will not show evidence for decades. In the USA, many cities have cast and ductile iron pipes, which have been buried for nearly 100 years or more, and these are now presenting ongoing issues to municipalities as they strive to upgrade their distribution/collection pipe network. This form of corrosion is dependent on the acidity of the soil pipes are buried, which can be further influenced by moisture content of soil and any soil contamination.



**Fig 2.2 - Graphitic Corrosion on Bell and Spigot Ductile Iron Piping**

#### KPI's of Coatings Intended for Graphitic Corrosion Exposures

- High tensile adhesion (>15 MPa) to better resist under film corrosion.
- High tensile properties for resistance to soil shear stress
- Impact and abrasion resistance for buried pipe
- Low permeability

### **2.3 Corrosion of Metals – Galvanic Corrosion**

This form of corrosion is caused by two dis-similar metals with different electromotive potentials being in contact with one another in the presence of a common electrolyte. The less noble metal becomes anodic in this case, and goes into ionic solution, sacrificing itself to protect its more noble cathode. The rate and severity of corrosion losses are related to electromotive potential differences between the anode and cathode, pH and conductivity of the electrolyte the dis-similar metals are exposed to, proximity of the two metals to one another, and finally the relationship of the anodic region's surface area compared to the cathodic region's surface area. If the anodic region is large compared to the cathodic region, corrosion rates will be slower than if the anodic region is significantly smaller than the cathodic region.

Treatment plant operators should be concerned with zinc galvanized surfaces in contact with unprotected carbon steel as well as aluminium structures such as trash racks or gates which might be electrically coupled to imbedded reinforcing rods in the concrete by way of carbon steel anchor bolts, carbon steel frames by way of anchor bolts.



**Fig 2.3 - Galvanic Corrosion of Aluminium Weir in Contact with SS Bolts**

KPI's of Coatings Intended for Galvanic Corrosion Exposures

- High tensile adhesion (>20 MPa) to resist under film corrosion
- High dielectric resistivity
- Resistance to cathodic disbondment
- Low permeability
- General resistance to thermal, chemical exposures

**2.4 Corrosion of Metals – Microbiologically Influenced Corrosion (MIC)**

MIC is commonly found in wastewater treatment collections and treatment facilities in both aerobic as well as anaerobic conditions. The primary form of MIC in wastewater treatment plants is biogenic sulphide corrosion which occurs when anaerobic sulphate reducing bacteria (SRB) metabolize the sulphate ( $\text{SO}_4^{2-}$ ) ions which are rich in the untreated wastewater flows. The SRB's metabolic process consumes oxygen, and the resulting by product is the sulphide ion ( $\text{S}^{2-}$ ). This ion is released into the water flows. The sulfide ions combine with hydrogen in the water flows to form hydrosulphide or bisulfide ( $\text{HS}^-$ ) ions. These ions react further to form hydrogen sulfide ( $\text{H}_2\text{S}$ ) which continues to build to saturation levels. In turbulent flows the  $\text{H}_2\text{S}$  gas, as well as carbon dioxide ( $\text{CO}_2$ ) are released into the humid enclosed head spaces commonly seen in manholes, wet wells and lift stations, junction boxes, collection pipe, junction boxes and then into the plant in bar screen chamber, grit chambers as well as primary and secondary clarifiers. These gases combine with the humid atmosphere and form weak thiosulphuric and carbonic acid which depresses the surface pH. Once the pH drops below 9.5, naturally occurring sulphur oxidizing bacteria (SOB) can colonize on the surface and they in turn metabolize the  $\text{H}_2\text{S}$  generating a weak sulfuric acid. This can result in surface pH <5. Mild steel and ductile iron, present in closed head spaces such as piping, valves, pumps, and associated structural members are then subject to accelerated corrosion rates from the acidic environment.



**Fig 2.4 – Biogenic corrosion of pipe brace/support in wet well**

## 2.5 Corrosion of Concrete - Microbiologically Influenced Corrosion (MIC)

The same processes stated above, that generates the dilute sulfuric acid, is present in enclosed head spaces of many wastewater associated concrete structures such as manholes, wet well/lift stations, junction boxes, collection pipe (force and gravity flow), bar screen chambers clarifiers and sludge tanks. Unfortunately, the corrosion reactions are significantly faster and more dramatic when concrete is the substrate exposed. This is primarily due to the alkaline nature of concrete (12.5 when freshly poured) reacting with the dilute sulfuric acid, which can easily assume pH levels of <2. The acid reacts with and converts the cement calcium hydroxide to calcium sulphate salts which are easily dissolved in water. This leads to the loss of the cement paste and the release of the aggregate and sand constituents in concrete, eventually exposing any structural members embedded into the concrete. The resulting surface can be exceptionally rough and difficult to coat with thin (<1mm) coatings.



**Fig 2.5 – Biogenic corrosion in enclosed head space of concrete bar screen chamber**

### KPI's of Coatings for Metal/Concrete Surfaces Intended for MIC Corrosion Exposures

- High tensile adhesion (>20 MPa) to resist under film corrosion on steel
- Resistance to Low pH (10% H<sub>2</sub>SO<sub>4</sub>)
- Resurfacing and barrier topcoats with edge retentive capability to prevent pinholes in applied films when being applied on heavily pitted surfaces
- Low surface energy to reduce biofilm build-up

## 2.6 Corrosion of Concrete - Acid Attack

The same acid base reaction occurs when many process chemicals used in wastewater treatments plants encounter unprotected concrete. Chemical attack occurs frequently when sulfuric acid is present and used as a buffer, as well as when ferric chloride and alum are used as flocculating agents. The areas which are more prone to attack tend to be containment and dose mixing stations, but the result is like MIC attack. Initially etching of the concrete, progressing as the cement paste is broken down, to exposed aggregate, and eventually, if left unaddressed to rebar corrosion and spalling.



**Fig 2.6 – Acid attack of concrete in sulfuric acid containment**

#### KPI's of Coatings for Concrete Surfaces Intended for Chemical Exposures

- Resistance to low pH from concentrated and dilute H<sub>2</sub>SO<sub>4</sub>, FeCl<sub>3</sub>, NaOH, NaOCl)
- Impact and abrasion resistance
- Low coefficient of thermal expansion for when thermal cycling exists
- Resurfacing and barrier topcoats with edge retentive capability to prevent pinholes in applied films when being applied on heavily pitted surfaces

### **3.0 CONCLUSION**

With increasing levels of urbanization reliance on and the corrosion effects on centralized wastewater treatment plants will continue to increase. While the effects of corrosion are unrelenting, a practical approach to selecting any protective coating program should be grounded in first understanding the varied corrosion mechanisms one may encounter. Once an understanding of what is occurring is arrived at the selection process for the proper coating should address the key performance indicators (KPI) of a coating deemed suitable for that environment ie. (low permeability, resistance to pH <1, edge retentive for MIC attacked concrete).

### **4.0 ACKNOWLEDGEMENTS**

I would like to thank my NACE instructor and mentor, Lou Vincent, who taught me that fighting corrosion is a worthwhile but never-ending battle against nature.

### **5.0 FOOTNOTES/REFERENCES**

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