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Corrosion of Steels in Irrigation Water Filtration Systems

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Introduction and Background:

Stainless steel has been in use in water filtration systems for approximately 20 years with a greater increase over the last ten years. The use of relatively thin (10-14 gage) stainless steel materials (when compared to mild steel vessels) has lead to premature failure of vessels under certain conditions. The majority of the failures investigated by our firm can be attributed to crevice and microbial corrosion.

One manufacturer [1] reports that the reduction in useful life of stainless steel to mild steel is more than a factor of two (10 versus 20 years). An estimated 10 to 15% of stainless steel vessels have experience pinhole corrosion failures within the first 2 years of service. In one application, approximately 30% of the stainless steel vessels failed due to corrosion within 5 years [1]. The same manufacturer reports that there have been no corrosion related warranty claims in more than 35 years with 50,000+ mild steel applications in irrigation water filtration.

Other manufacturer's contacted [2, 3] reported failures associated with welds and stress risers in stainless steel systems. All manufacturers contacted said that failures were generally associated with high chloride waters and all reported failures associated with welds (see photo on left below). Two manufacturers indicated that the desire for stainless steel by the market was driven by the desire to reduce painting maintenance and not due to corrosion or other failures of mild steel systems [1, 3].

Failures of Stainless Steel Filtration Vessels by
Crevice Corrosion (left) and Microbiological Corrosion (right)

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Contrary to popular belief, stainless steels are not immune to all types of corrosion [4]. Stainless steels, like any other alloy system including mild steel, should be used under environmental conditions that exploit their unique corrosion control characteristics. Unfortunately, the conditions under which failures of stainless steel will occur are not always clear and field conditions can and do change over the useful service life of the filtration system.

Corrosion Control for Stainless and Mild Steel:

The mechanisms and methods of corrosion protection for stainless steel differ from that of carbon steels in filtration systems. The majority of carbon steel vessels have been manufactured with bare internal metal surfaces. In these cases, corrosion protection is provided by the formation of the natural barrier oxide coating (rust) that separates the metal from the surrounding environment. The degree of protection provided by the oxide film is a function of the thickness and physical characteristics of the oxide. Once the oxide forms and thickens over time without disruption, corrosion protection is good unless the film is mechanically removed [4]. In addition, if water chemistry conditions are right, calcareous (calcium-rich) deposits from the water can provide a "self-healing" protective film on the surface of the metal or oxide.

In some cases with carbon steel, mechanically adherent and tough organic coatings, such as epoxies, have been used as the primary corrosion protection system. In these cases the dielectric coating acts as the barrier between the metal and the environment. The use of dielectric coatings alone for corrosion protection does not guarantee corrosion protection since coating imperfections or "holidays" can allow contact with the environment. The corrosion protection of the organic coating can be supplemented by the use of a sacrificial anode. The combination of the epoxy coating with a sacrificial anode is a proven engineering solution to corrosion control in water systems [5].

Stainless steels exhibit good general corrosion resistance in aerated water environments. Corrosion protection is provided by the formation of a relatively thin passive film that forms on the surface of the stainless steel if water and physical conditions are right. Passivation refers to the naturally formed "coating" on the surface of stainless steel. In general, if the water environment is aerated and the oxygenated water can reach the surface of the stainless steel, then the passive film forms, remains intact and provides excellent corrosion resistance.

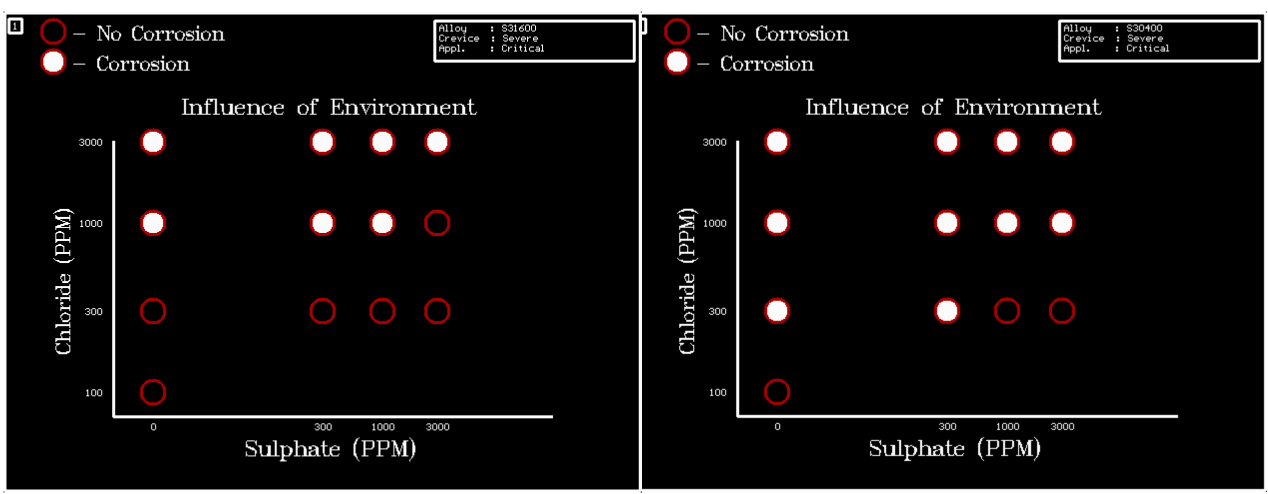
A corollary to their good general corrosion resistance is the fact that stainless steels are susceptible to localized forms of corrosion, such as pitting, crevice, stress cracking, etc. Localized corrosion problems arise when conditions within the tank construction or the water prevent formation of the passive film on some part of the stainless steel surface. In these situations, one portion of the stainless steel corrodes (the anode) to "protect" another portion of the metal (the cathode). For example, when pitting occurs, the bottom of the pit corrodes as the anode to protect the cathodic area (metal) adjacent to the opening of the pit. Eventually, the bottom of the pit can perforate the metal with a pinhole, while the vast majority of the stainless steel exhibits little or no corrosion.

One possible explanation for the difference in service life performance between stainless and mild steel may be as simple as the thickness of the material used for construction and the difference in the mode of corrosion damage between the two materials. Typically, mild steel systems use a minimum of 3/16" (0.1875") thick plate for fabrication and general (uniform) corrosion is the primary mode of corrosion damage. Stainless steels in filtration systems range from 10 gage (0.135") to 14 gage (0.075") thickness and localized corrosion (crevice, pitting or microbiological corrosion) is the mode of corrosion damage. Since localized corrosion rates tend to be much greater than uniform corrosion rates, thinner members subjected to localized corrosion could fail in significantly shorter periods of time as compares with thicker members subject to uniform corrosion.

Crevice Corrosion:

Crevice corrosion is a form of localized corrosion that is similar to pitting [4]. Crevice corrosion occurs when any physical situation restricts access of oxygen to the surface of the material. By contrast, pitting usually initiates at metallurgical features present in the microstructure of the material. Crevice corrosion occurs at features inherent to the structure due to design, fabrication or operation (gaskets, lap welds, filtration media/metal interface, pockets of debris, etc.).

The resistance of a stainless steel alloy to crevice corrosion is related to the composition and product form of the stainless steel, the severity of the crevice and the environment. Two of the most common grades of a stainless steel are type 304 and 316. The figures below show that, although some improvement in crevice performance is gained by changing the alloy from type 304 to type 316 stainless steel, crevice corrosion can persist. Further, increases in crevice corrosion resistance can be made with additional changes (increases) in alloy composition, but these improvements in corrosion resistance generally involve higher material cost and, possibly, changes in fabrication processes.



Crevice Corrosion Resistance Maps [6]
Type 316 Stainless Steel (left) and Type 304 Stainless Steel (right)

Because of the nature of the filtration media and fabrication methods, it is virtually impossible to eliminate crevices from sand media filtration vessels. In addition, without proper flushing and maintenance, local water chemistry in stagnant areas could result in crevice corrosion failures.

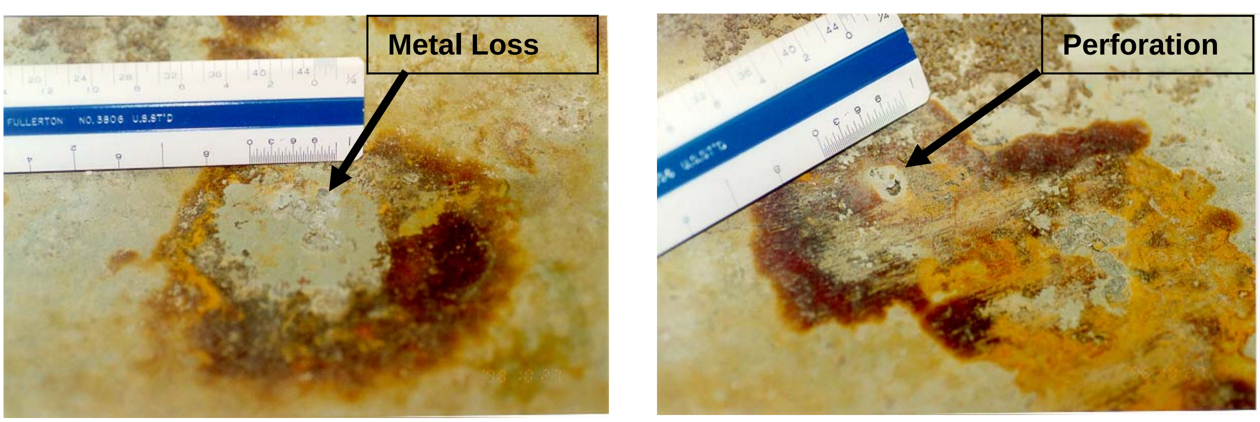
Mild steel can exhibit crevice behavior, but in general, in the same environment, stainless steel will exhibit more severe crevice corrosion due to its mechanism of corrosion protection (i.e. formation of passive film).

Microbiological Corrosion:

Microbiological corrosion (MIC) refers to corrosion and ensuing loss of metal caused by biological organisms [7]. MIC can occur in any aqueous environments, and because of the omnipresent nature of microbes in agricultural and groundwater systems, MIC is a common phenomenon. MIC is a common problem in industrial and agricultural processes due to the presence of microbes, adequate nutrients and their corrosive byproducts.

As mentioned above, the corrosion on stainless steels is determined by the rate at which oxygen in solution is be delivered to the metal surface. Biological organisms present in the aqueous medium often tend to increase or decrease oxygen transport to the surface; consequently, these organisms have a role in increasing or decreasing corrosion. Most MIC shows up as localized corrosion because most organisms do not form a large continuous film on the metal surface. Microscopic organisms tend to settle on metal surfaces in the form of discrete, spotty colonies, rather than continuous films.

Biological organisms that cause corrosion on metals fall into two groups based on the conditions under which they occur: Anaerobic and aerobic conditions. Sulfate reducing bacteria (SRB) are a typical example of anaerobic MIC and occur when conditions in the environment are oxygen free. Aerobic sulfur-oxidizing bacteria that can occur with oxygen present can create an environment of up to 10 percent sulfuric acid, thereby encouraging rapid localized corrosion.



Close-up Photos of MIC Corrosion on Stainless Steel Filtration Vessel Heads
(Note localized colony formation and perforation/loss of metal)

MIC can occur on mild steel. However, similar to crevice corrosion, MIC for agricultural filtration systems appears to be more prevelant with type 304 and 316 stainless steels.

The best method for controlling MIC is to eliminate the bacteria with water treatment (biocide). For agricultural purposes, it may not be desireable or cost effective to apply a biocide to treat the water. Other corrosion control methods should be considered.

Corrosion Control Strategies:

For stainless steels, improving alloy composition or use of coatings and sacrificial anodes can, in some instances, be used to solve both crevice corrosion and MIC. Increasing alloy composition can change material and fabrication costs. In addition, application of coatings to stainless steels can be difficult and expensive. Sacrificial anode performance should be similar for either stainless or mild steel, if both interiors are coated.

For mild steel, the performance of uncoated steel has been historically good. If additional corrosion protection is desired, high quality dielectric coatings, such as polyamide epoxies, as the primary corrosion protection with and without sacrificial anodes have been an effective corrosion control strategy. Because of the differences in mechanisms of corrosion protection, mild steel can be less susceptible to crevice corrosion and MIC as compared to stainless steel. Again, the improved performance may be due in part to the fact that mild steel filtration vessels are, in general, thicker than stainless steels used for filtration systems.

Mild steel systems do suffer from a maintenance issue in that if the exterior coatings are not maintained, rust will form and spoil the appearance of the system. In general, unpainted stainless steel exposed to atmospheric conditions will require little or no maintenance to preserve its aesthetics. Unfortunately, localized corrosion on the internal stainless steel surfaces of the vessel can prematurely terminate the useful service life of the system.

Conclusions and Expectations:

In any engineering system, corrosion control measures should be considered and based on required service life, anticipated service/operating conditions and previous experience in the service environment. The level of corrosion protection is up to the end user to choose at the time of construction or purchase.

Crevice and microbiological corrosion of stainless steels in sand filtration vessels can and have lead to reduced useful service lives in some applications. The conditions under which these failures will occur are difficult to predict because water chemistry/conditions change and operating conditions and procedures may impact the corrosion mechanisms. Improved materials selection can reduce, but not eliminate, the risk of localized corrosion for stainless steel. Increased material costs and changes in fabrication processes may be associated with a change in alloy.

Mild steel has historically performed well in water filtration systems even with little or no additional corrosion control measures. Some of the increased service life may be due to the use of thicker material for mild steel as compared to stainless steel. Maintenance issues do exist with mild steel, which in most cases do not exist with stainless steel. The value of this historical performance should not be diminished due to maintenance and cosmetic concerns.

References:

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