



PLANK ROAD
TECHNOLOGIES, LLC

Corrosion Prevention of Carbon Steel in Standing Water

MOTIVATION

Controlling the storage environment of high value equipment and parts is essential to cutting costs in time spans when assets are not utilized in their designed applications. Extreme conditions where liquid water is in contact with integral metal components of the asset cause rapid corrosion. Consequently, corrosion prevention in applications storing pressure vessels or heat exchangers can be challenging because these enclosures tend to trap moisture. Therefore, it is possible for standing water to be present during storage. With the removal of dissolved oxygen from standing water it is possible to prevent the corrosion of submerged metal components.

A common method of corrosion prevention in heat exchangers and pressure vessels is first vacuuming out the enclosures air then replacing it with a nitrogen buffer. This method does remove moisture and oxygen; however, the effectiveness of this method relies on long treatment periods and is more expensive and less effective than Plank Road Technologies' patented Corrosion-Prevention-System (CPS). The Low-Oxygen-Content (LOC) in the CPS, rather than first vacuuming then injecting a nitrogen buffer separately, performs both operations concurrently, and in a shorter time span. Additionally, the LOC system does not use nitrogen from tanks; instead, nitrogen is separated and collected from the air inside the enclosure or that of the surrounding atmosphere. Plank Road Technologies' CPS is known to provide extraordinary corrosion protection in environments plagued with moisture. With the knowledge that some applications suffer from corrosion caused by standing water in the storage environment, it became necessary to determine if the CPS system could provide a robust solution for this challenge.

Note: Carbon steel was used in this experiment because it is highly susceptible to corrosion.

Note: In addition to corrosion, the CPS protects against all other forms of degradation caused by moisture and oxygen.

EXPERIMENTAL PROCEDURE

The purpose of this research was to determine if the CPS has the capability to inhibit corrosion in extreme cases where unprotected carbon steel would be in direct contact with standing water. The goal was to create a worst-case environment with an abundance of water that would simulate conditions that cause corrosion on internal surfaces of heat exchangers and pressure vessels in storage. Two samples of carbon steel rebar were sanded and polished to remove any protective coating. These samples were then submerged in separate containers of water to serve as analogues for metal surfaces in these extreme storage environments. Plank Road Technologies' Oxygen Barrier SecurePac was used to fabricate the enclosure that housed the Test sample. The SecurePac has barrier properties that can simulate the impenetrability to gases that heat exchangers and pressure vessels exhibit. The atmospheric conditions inside the enclosure were then modified by recirculating the air of the enclosure through a closed loop system that removes oxygen, moisture, and particulates from the air. When the oxygen levels were close to zero, the LOC system was readjusted to pressurize the enclosure with nitrogen collected from ambient air. The second sample was submerged in water and left to serve as the Control for the experiment. Data was collected over a period of thirty days with monitoring equipment to measure temperature, humidity, and oxygen levels in both the air and water. The data collected throughout the duration of the experiment can be observed and analyzed in the Figure below.

Corrosion Test with Submerged Sample

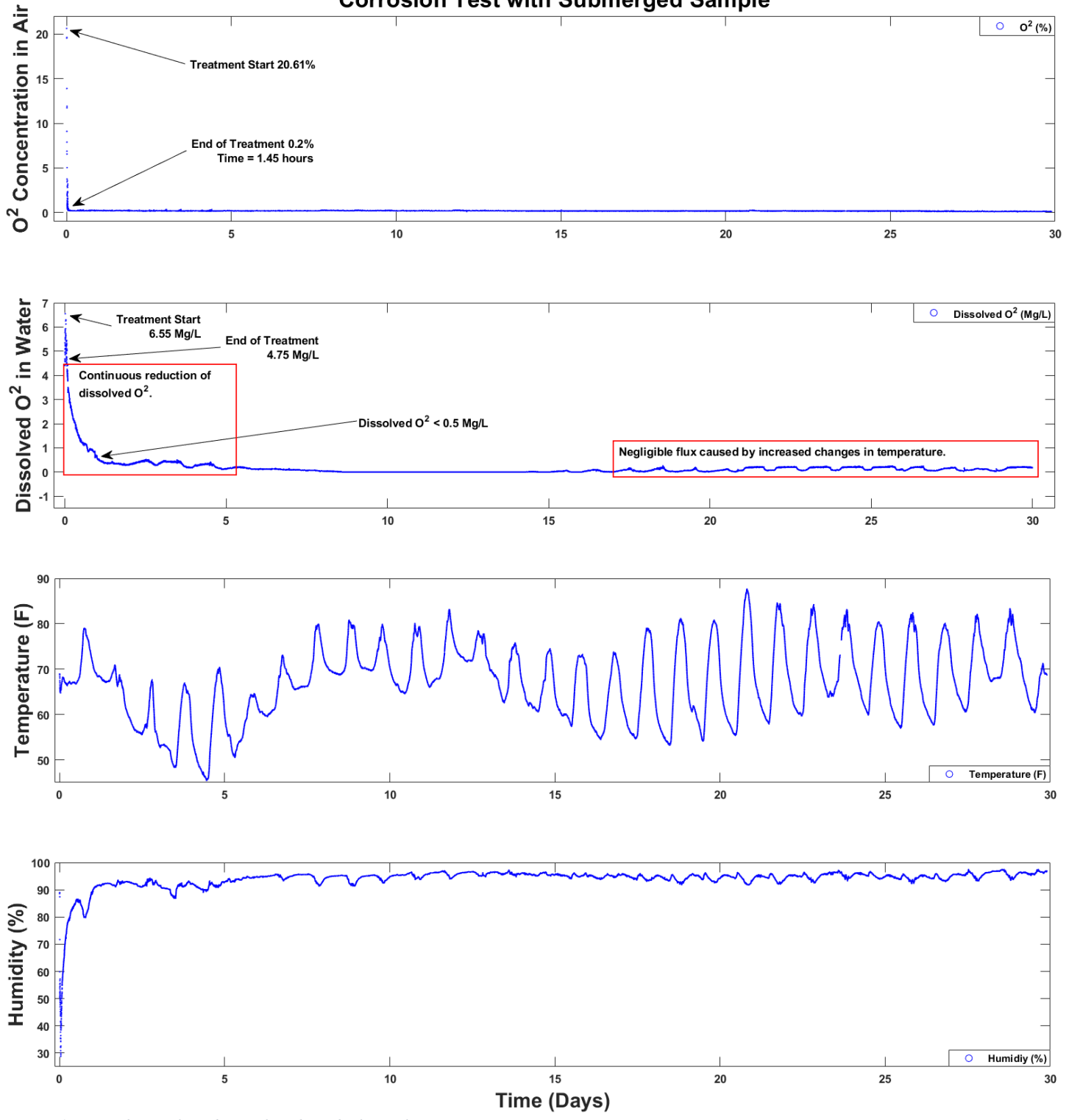


Figure 1: Data charts of conditions found inside the enclosure.

Within 1.45 hours the LOC System decreased the oxygen concentration in the enclosure from ambient levels to 0.2%. The oxygen concentration that was obtained during the treatment phase was stable for the duration of the test. Immediately following treatment, it was evident that dissolved oxygen levels in the water surrounding the sample were decreased and continued to decline. Within a single day the dissolved oxygen fell to less than 0.5 Mg/L and later stabilized at values less than 0.1 Mg/L. Minor fluctuations in dissolved oxygen values driven by larger bands of temperature flux occurred between 17 days and the end of the test. The highest dissolved oxygen value observed in the period of fluctuation was 0.2 Mg/L. Temperature data in Figure 1 verifies that an increased temperature flux occurred and continued after 17 days. Relative humidity data, although not directly related to corrosive reactions of the submerged sample, is useful to indicate the presence of standing water in a sealed environment. Once the thirty-day experiment was complete, the Test sample was removed from the enclosure to document the material quality for comparison against the Control sample.

RESULTS AND DISCUSSIONS

Observation of the Test sample conducted after the thirty-day period provided extraordinary results for corrosion protection. The Figures below show the quality of both Control and Test samples before and after completion of the corrosion experiment.



Figure 2: Control sample at start of test.



Figure 3: Control sample after completion of the test.

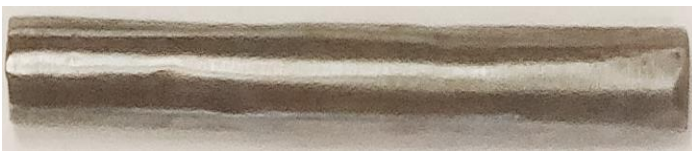


Figure 4: Test sample at start of test.



Figure 5: Test sample after completion of the tests.

The Control sample in Figures 2 and 3 was heavily corroded at the end of the thirty-day test. Despite a thirty-day submersion period there is no observable difference in the quality of the Test sample in Figures 4 and 5. Further investigations were conducted to provide evidence that even slight surface corrosion, too small to view with the naked eye, was not present in Figure 5. To prove this, the capture of high-resolution images of a cross-section from the Test sample in Figure 5 made it possible to examine surface patterns in fine detail. Emory paper, a common type of sanding paper used to polish metals, was utilized to polish both samples before the test was conducted. Consequently, the polishing process creates tiny striations in the metal that are observable in high resolution images. If corrosion reactions occur on the sample bar, the surface pattern from polishing quickly degrades. Below, Figures 6 and 7 contain the high-resolution images from cross-sections of the Test sample and Control sample after completion of the thirty-day experiment.

NOTE: The surface corrosion on the control sample was cleaned off to observe surface striations.



Figure 6: Cross-section of Test sample.

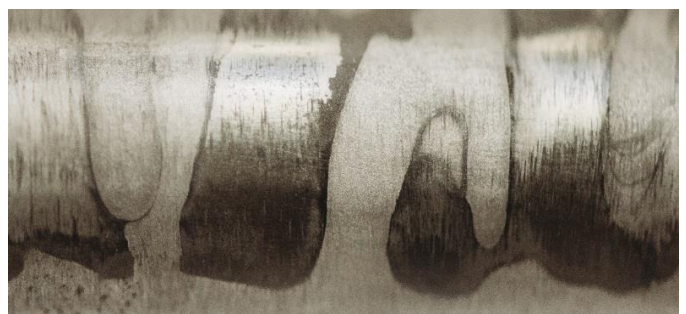


Figure 7: Cross-section of Control sample after removing rust.

The surface striations in Figure 6 were not lost during the time of submersion in the experiment. Additionally, no observations finding signs of even minute corrosion on the surface of the Test sample were found. In Figure 7 evidence of corrosion is prominent on the surface of the Control sample. The first sign of corrosion is the dark patches of grainy material clinging to the surface. In between the dark patches a smooth, metallic surface lacking striations dominates the space. The lack of surface striations and the darkened surface is

clear evidence of the corrosive process that occurred on the Control sample. Further examination of the smooth surfaces in Figure 7 showed that these regions had corroded more dramatically than the surrounding material.

CONCLUSIONS AND FUTURE RESEARCH

Based on the results in this experiment, the novel process of utilizing Plank Road Technologies' CPS in combination with the LOC System has demonstrated tremendous effectiveness in removing dissolved oxygen in water - in addition to oxygen in air - down to values close to zero. Consequently, the water was incapable of corroding the carbon steel rod because oxygen is essential to the chemical process of metal corrosion. Utilizing this method of corrosion prevention, the LOC system can provide a robust storage solution to combat environmental variables that exist in sealable enclosures, be they rigid or flexible. To further the research exhibited in this report, the same experiment is currently being conducted with salt water. The salt in the water only accelerates the corrosion reaction of the metal with oxygen. Therefore, the method of corrosion prevention employed in this subsequent test is expected to yield equivalent results to the findings of this report.