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HANFORD DOUBLE SHELL WASTE TANK CORROSION STUDIES – FINAL REPORT FY2015

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EXECUTIVE SUMMARY

During FY15, SRNL performed corrosion testing that supported Washington River Protection Solutions (WRPS) with their double shell tank (DST) integrity program. The testing investigated six concerns including, 1) the possibility of corrosion of the exterior of the secondary tank wall; 2) the effect of ammonia on vapor space corrosion (VSC) above waste simulants; 3) the determination of the minimum required nitrite and hydroxide concentrations that prevent pitting in concentrated nitrate solutions (i.e., waste buffering); 4) the susceptibility to liquid air interface (LAI) corrosion at proposed stress corrosion cracking (SCC) inhibitor concentrations; 5) the susceptibility of carbon steel to pitting in dilute solutions that contain significant quantities of chloride and sulfate; and 6) the effect of different heats of A537 carbon steel on the corrosion response. For task 1, 2, and 4, the effect of heat treating and/ or welding of the materials was also investigated. A brief summary and conclusions for each of the studies conducted is presented below.

1. **Secondary wall of AY-102 tank corrosion studies**

Total immersion (TI) and VSC studies were executed in simulated leak detection pit (LDP) and ground water (GW) simulants that are representative of the potential liquids present at the secondary wall of AY-102. Refractory waste simulants (i.e., AY-102 waste simulant that has contacted the refractory pad) were also studied, but only for VSC. During TI tests, general attack was observed on all samples exposed to the GW and LDP simulant. The rate was constant at approximately 10 mpy over the four month exposure period for coupons exposed in GW simulant. In contrast, the corrosion rate for coupons exposed to the LDP simulant were higher for the initial two months and then decreased during the final two months of exposure to approximately half of the initial rate. Generally, the corrosion rate and the open circuit potential did not depend on the heat treatment and no distinctive corrosion patterns were observed in the weld region. For VSC testing, corrosion was more severe for coupons exposed above the GW simulant than the LDP simulant. In general, coupons close to the liquid level corroded significantly more than those located well above the liquid air interface. For the refractory simulants, a small degree of surface attack was observed, however, almost no weight loss was measured after four months of exposure. The high nitrite concentration at these conditions was a contributing factor for inhibiting corrosion.

2. **Vapor space corrosion tests at the new SCC limits with different concentrations of ammonia gas in air**

A 0.4 M nitrate simulant, prepared according to the proposed new limits for stress corrosion cracking (SCC), was used to perform VSC test in atmospheres that contained between 50 and 550 ppm of ammonia. After four months of exposure, corrosion was more severe at the level next to the LAI than at the two higher levels. Coupons at the LAI had varied corrosion rates, whereas the coupons at the higher levels exhibited negligible corrosion. The corrosion rate did not depend on the heat treatment of the material or on the ammonia concentration present in the atmosphere.

3. **Waste buffering of simulant from DST AN-102**

AN-102 simulant was utilized to investigate waste buffering at different concentrations of nitrate, nitrite and hydroxide. Eighteen tests were performed over a large range of nitrate (1.1 to 5.5 M), nitrite (0.5 to 1.5 M), and hydroxide (0.01 and 0.05 M) concentrations at 40 °C. No pitting susceptibility was observed when the concentration of nitrite was increased to 1.5 M at 0.01 M hydroxide or increased to 1.0 M at 0.05 M hydroxide independent of the nitrate concentration. Therefore, at low temperatures (i.e., less than 40°C) the amount of free hydroxide necessary to inhibit pitting was less than that required by the current waste chemistry control program provided there is sufficient nitrite present.

4. Liquid air interface tests at the new SCC limits

LAI tests of carbon steel coupons exposed to simulants with different ratios of nitrite and nitrate were performed. Coupons exposed to simulants with a ratio of nitrite to nitrate of 1.66 showed negligible corrosion rates or pitting susceptibility. This can be expected since this inhibitor ratio meets the SRS requirement for pitting control. None of the coupons showed any signs of LAI. Minor areas of general surface attack were seen in the vapor space area. However, no pits or general corrosion areas were observed in the weld area of the coupons. There was also no correlation between heat treatment and the degree of corrosion observed.

5. Pitting corrosion studies using the standardized CPP protocol for the Argentinian work and additional dilute test solutions

The results of the 18 repeated Argentina tests compared relatively well to original CPP test results. A second series of tests in simulants with nitrate concentrations ranging between 0.5 – 2 M resulted in 11 of the 12 cases indicating pitting. These results indicate that a pH of 12 is not always sufficient to prevent pitting initiation particularly if higher than normal quantities of chloride and sulfate are present. The results from these tests, along with other previous testing, will be utilized during FY16 for the development of new corrosion chemistry limits for pitting prevention.

6. Pitting corrosion studies using the standardized CPP protocol of new vs. legacy stock of A-537 steel for vitrification return stream

All five heats of A-537 carbon steel underwent aggressive pitting corrosion in the two test simulants during the CPP test. To determine if there is an appreciable effect of the different heats of material, CPP testing in a simulant that is not aggressive and in one that produces mixed results may reveal differences (i.e., similar to the test protocol development).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CPP	Cyclic Potentiodynamic Polarization
DNV-GL	Det Norske Veritas-Germanisher Lloyd
DST	Double-Shell Tank
DWPF	Defense Waste Processing Facility
EPOC	External Panel Oversight Committee
GW	Ground Water
HAZ	Heat Affected Zone
LAI	Liquid-Air Interface
LDP	Leak Detection Pit
OCP	Open Circuit Potential
PNNL	Pacific Northwest National Laboratory
SCC	Stress Corrosion Cracking
SCE	Saturated Calomel Electrode
SRNL	Savannah River National Laboratory
SST	Single-Shell Tank
TI	Total Immersion
TIEP	Tank Integrity Expert Panel
VS	Vapor Space
VSC	Vapor Space Corrosion
WRPS	Washington River Protection Solutions

1.0 Introduction

Double shell tanks (DSTs) at the Hanford Site are constructed of carbon steel have a detailed waste chemistry control program to prevent corrosion. The DSTs have been used to store waste from older single-shell tanks (SSTs), while the Waste Treatment and Immobilization Plant (also known as the Vit Plant) is constructed. Waste chemistry control is of great importance as it can help to maintain structural integrity of the tank by reducing the likelihood of significant corrosion.

The Tank Integrity Expert Panel (TIEP) provides guidance to the Hanford Site regarding testing to support corrosion control for the DSTs. This panel is a consolidation of the Expert Panel Oversight Committee (EPOC), High Level Waste Integrity Assessment Panel and Single Shell Tank Integrity Panel. Three laboratories continue to be involved in corrosion testing: Det Norske Veritas-Germanischer Lloyd (DNV-GL), Savannah River National Laboratory (SRNL), and the 222-S facility at Hanford currently operated by Washington River Protection Solutions (WRPS).

During FY15, SRNL performed corrosion testing that supported Washington River Protection Solutions (WRPS) with their double shell tank (DST) integrity program. The testing investigated six concerns including, 1) the possibility of corrosion of the exterior of the secondary tank wall; 2) the effect of ammonia on vapor space corrosion (VSC) above waste simulants; 3) the determination of the minimum required nitrite and hydroxide concentrations that prevent pitting in concentrated nitrate solutions (i.e., waste buffering); 4) the susceptibility to liquid air interface (LAI) corrosion at proposed stress corrosion cracking (SCC) inhibitor concentrations; 5) the susceptibility of carbon steel to pitting in dilute solutions that contain significant quantities of chloride and sulfate; and 6) the effect of different heats of A537 carbon steel on the corrosion response. For concerns 1, 2, and 4, the effect of heat treating and/ or welding the materials was also investigated.

2.0 Background

For FY15, SRNL developed a Task Plan with five tasks for corrosion testing during the fiscal year. This task plan focused on long term testing for VSC and LAI and pitting corrosion performing electrochemical techniques [1]. A brief background will be provided in the following sections and how it aligned for FY15 testing.

2.1 Vapor space corrosion testing at SRNL

Testing of VSC at SRNL provided the foundation for the prevention of this type of corrosion in the DSTs at Hanford. Historically, there have been unexplained cases of corrosion of equipment that was suspended in the vapor phase of these tanks. However, no consequential incidents of uniform or localized corrosion have occurred. The chemistry in the vapor phase provides a challenge because once vapor condenses on the walls of the tank, the chemistry can evolve depending on the constituents and level of evaporation of the condensate. This can influence the formation of corrosion products and corrosion of the steel. There have been previous explorations to understand the mechanism behind VSC: the chemical composition of the liquid that condensed in carbon steel in vapor phase [2] and corrosion above simulated waste environments [3],[4]. Several VSC tests were performed at SRNL in representative vapor space condensates for the DSTs, which were predicted from thermodynamic calculations and experiments performed by Pacific Northwest National Laboratory (PNNL) [3]. They found that ammonia and carbon dioxide were the dominant species in the vapor phase that are most likely to affect carbon steel corrosion.

Ammonia is produced predominantly in the supernate through thermal and radiolytically induced reactions between organic waste components and nitrate and nitrite ions. The concentration in the vapor space varies but it can be as high as 550 ppm (obtained in Tank SY-102). Experimental testing has shown that VSC can be inhibited by the presence of ammonia [5],[6].

Corrosion chemistry limits were recommended to minimize SCC in the DST [7]. Table 2-1 lists the different specifications and the maximum or minimum requirements needed for SCC control. The specific limit of interest for current testing is the minimum nitrite/nitrate ion ratio of 0.15 with minimum nitrite concentration of 0.05 M. For nitrate concentrations of 0.4, 2 and 4.5 M the minimum ratio of 0.15 was not able to prevent pitting corrosion in the VS but it was prevented in most cases by flowing 550 ppm of ammonia [4].

Table 2-1 Proposed Specifications for the Control of SCC in Nitrate Ion Wastes in DSTs.

Maximum Temperature	50 °C
Maximum Concentration of Nitrate Ion	6.0 M
Maximum Concentration of Hydroxide Ion	6.0 M
Minimum pH	11
Minimum Concentration of Nitrite Ion	0.05 M
Minimum Nitrite Ion/Nitrate Ion Ratio	0.15

During FY14, testing was performed at different levels above the liquid to assess differences as a function of height [8]. Three levels were selected: low (Level 1), intermediate (Level 2) and high (Level 3). Humidified ammonia flowed at 50 and 550 ppm in vapor space of simulants containing the minimum nitrite/nitrate ratio of 0.15 and nitrate concentrations of 0.4, 2 and 4.5 M. After four months of continuous exposure there was no indication of VSC at levels 3 and 2 with minor corrosion areas at Level 1 for the 550 ppm ammonia in each of the simulants. The same was true at 50 ppm, as there was no significant VSC. However, some crevice corrosion was observed around the edges of most coupons. A reason for this was the use of acrylic mount in which it did not provided a very high adhesion into the edges of the coupon. Still, it was observed that even at 50 ppm ammonia with solutions comprised of the new SCC control limits VSC can be inhibited.

VSC testing was also performed with simulants for the leak detection pit (LDP) and ground water (GW) at the exterior of tank AY-102 [8]. A more prominent corrosion attack was observed for coupons exposed to GW simulant than the coupons exposed to LDP residue. More aggressive attack was observed on the samples closest to the liquid level (Level 1 > Level 2 > Level 3) for the coupons from GW simulant.

2.2 Liquid-Air Interface Corrosion testing at SRNL

Corrosion at the liquid air interface (LAI) can develop when the liquid level remains stagnant for some period of time. Only one instance was seen at Hanford (Tank AY-101) [9]. During testing LAI corrosion was also observed by DNV-GL in tank AP-105 [10]. Other studies were made after that to understand the mechanism behind it [10]-[12]. Up to this point a clear mechanism has not been developed and several findings identified that LAI corrosion cannot be fully simulated. However, testing with different chemical compositions can provide guidance to minimize or prevent it.

At SRNL, the study of LAI corrosion has been done in the past several years to study corrosion at the interface for the new control limits for SCC [13]. These tests demonstrated that the minimum ratio of nitrite to nitrate of 0.15 was insufficient to prevent corrosion at the LAI. For FY14, eight different solutions were prepared with compositions that were at or near the new SCC control limits [8]. After four months testing there was no indication of LAI corrosion and most samples corroded in only the VS. This VS corrosion appeared to be more severe for the more dilute solutions at a given nitrite/nitrate ratio.

LAI testing, as well as Total Immersion (TI) testing, was performed for carbon steel exposed in LDP and GW simulants [8]. After just two months, aggressive corrosion was sustained for all samples. For the partially immersed samples after two months of exposure, the corrosion occurred at the water line and below. By the fourth month, the corrosion increased above the water line of the coupon as well. The corrosion rate was steady for the 4 months test at approximately 10 mpy. A similar corrosion rate was observed for samples that were completely immersed in the LDP and GW simulants.

2.3 Waste Buffering Corrosion Studies

Grab samples from AN-102 at six different levels within the supernate, were analyzed to determine the chemical composition in 2012 [14],[15]. It was found that while sufficient nitrite inhibitor was present, the hydroxide concentration was near or below the minimum requirement. Electrochemical testing revealed that the carbon steel was not susceptible to pitting corrosion in the actual waste chemistry [14]. Other electrochemical experiments were performed with AN-102 simulants with lower hydroxide concentrations that were less than the actual waste and corrosion chemistry requirements [16]. It was found that carbon steel is mildly susceptible to corrosion in these environments. Both of these test programs were conducted prior to the round robin testing that was performed to develop a standardized CPP test protocol [17]. This protocol is described in Table 2-2.

Table 2-2 Standardized CPP protocol with the parameters utilized for testing

Parameters	Results
Potential Stabilization (hrs.)	2
Start Potential (V vs. OCP)	-0.05
Scan Rate (mV/s)	0.167
Vertex Threshold (mA/cm^2)	1
Finish Potential (V vs. OCP)	0
Sample geometry	bullet
Surface Preparation	600 grit

During FY14, some of the tests were repeated using the standardized CPP protocol [8]. Low levels of hydroxide were used in combination with different nitrate and nitrite concentrations. No pitting was observed in any of the samples. The results showed that hydroxide concentrations as low as 0.032 M can still offer inhibition for corrosion in carbon steel provided sufficient nitrite is present. LAI tests were also performed and correlated well with electrochemical experiments.

2.4 Electrochemical Studies for pitting corrosion

Cyclic potentiodynamic polarization (CPP) tests, which are utilized to assess pitting susceptibility of a material in a given environment, have been standardized for application to the Hanford DSTs. During FY14, testing was conducted to compare historical data that was obtained with other protocols with a purpose of determining the effect of CPP parameters on the results [8]. Forty test conditions were selected using a statistical design to represent a significant area of the more than 900 historical tests conditions. In general, the cases of clear-cut pitting or no pitting were in agreement, and consistencies in CPP data obtained with the new protocol with the historical data for the cases where pitting was found.

For FY15, the focus was placed in using the standardized CPP protocol with data obtained at Argentina specifically. This work was performed in 2004 at the Comisión Nacional de Energía Atómica in Buenos Aires [18]. The study was a joint effort to investigate solution chemistry that will impact the waste storage at the Hanford DSTs during future tank operations. In addition to these tests, 12 tests were selected to investigate the region from 0.5 M to 2.0 M nitrate. The effects of chloride and sulfate on pitting corrosion were investigated with these tests.

2.5 Material Selection Studies

The corrosion resistance of modern steel alloys may slightly different than that of legacy materials. For FY15, testing was conducted on modern alloys from 4 different manufacturers and compared to legacy steel of the same grade. This study will help direct the selection and specification of materials used in repairs and replacements of containment and infrastructure.

3.0 Task Description and Activities

Several tasks were performed during FY15 and are described in the sections below.

3.1 Task 1: Vapor space Corrosion Studies for Hanford Double Shell Tanks

Experiments were conducted during a period of four months with low nitrate solutions at two different gaseous concentrations of ammonia in vapor space to investigate ammonia inhibition. Additionally four more experiments were performed. Two of these experiments investigated the effects on refractories residues that occur between the carbon steel and refractory lining between the primary and secondary tank from simulated residues from tank AY-102. The other two experiments investigated VSC above simulated LDP and ground water solutions of this same tank. Carbon steel coupons used for this test were obtained from a welded part of a panel with different heat treatments: (1) no heat treatment, heat treated at (2) 1200 °F and (3) 1600 °F. They were located at three different levels above the simulant to mimic different conditions inside the DST. These conditions were (1) the carbon steel is exposed to a wet/dry cycle with the waste; (2) the carbon steel was wetted at some point but now is only exposed to humid air and (3) carbon steel that was never wetted by the waste and therefore only exposed to humid air. The results for this task are presented in subsection 5.1.2 for the conditions near the secondary liner of Tank AY-102 and section 5.2 for the simulants with a low nitrate simulant from the new control limits for SCC adding humidified ammonia in the vapor phase.

3.2 Task 2: Liquid Air Interface Corrosion Testing

Long-term corrosion testing with carbon steel coupons immersed at the LAI were performed using rectangular carbon steel coupons. The carbon steel coupons used were obtained from a welded section of a panel with different heat treatments: (1) no heat treatment, heat treated at (2) 1200 °F and (3) 1600 °F. The specimens were tested to determine the susceptibility for LAI corrosion in several simulants at different nitrite and nitrate concentrations and ratios. Also TI coupons were tested for long-term corrosion from a simulated environment at the exterior of the secondary wall of tank AY-102. The results obtained for this task are presented in subsections 5.1.1 for the conditions near the secondary liner AY-102 and section 5.3 for LAI tests at the new SCC limits.

3.3 Task 3: Pitting Corrosion studies

Electrochemical experiments were performed to compare results using the standardized CPP protocol to the Argentinian data that was previously reported before this protocol was created. The results are organized in section 5.4.

3.4 Task 4: Waste Buffering

Simulants, based on samples of actual waste from Tank AN-102, were utilized to perform electrochemical tests. The tests were continued from FY14 to address other concentrations that may influence pitting corrosion at minimum hydroxide concentrations. These results were gathered with the standardized CPP protocol and are presented in section 5.5.

3.5 Task 5: Material Selection

Testing on four modern alloys and the legacy stock of A-537 steel was performed electrochemically to determine the propensity for localized corrosion. The results were obtained using the standardized CPP protocol and are presented in section 5.6.

4.0 Experimental Procedure

Carbon steel coupons were used for corrosion testing and analysis. They were fabricated from AART128 Rail Car Steel. This steel was selected for testing since it approximates the chemistry and microstructure of American Society for Testing and Materials (ASTM) A515 Grade, Grade 60 carbon steel, the steel from which the tanks were fabricated [19]. DNV-GL classified this material as DNV-GL ID# 2232. This steel has an approximate vintage as the tank steel. The chemical composition of the steel is shown in Table 4-1.

Table 4-1 Chemical Composition of AART128 Rail Car Steel

	C	Mn	P	S	Si	Fe
Specification (wt%)	0.24 (max.)	0.9 (max.)	0.035 (max.)	0.04 (max.)	0.13 to 0.33	Balance
Measured (wt%)	0.212	1.029	0.012	0.013	0.061	Balance

For Task 1 and 2, the specimens of carbon steel were obtained from a plate of DNV-GL ID# 2232 that was welded in the center of the plate. For Tasks 3 and 4, the material used was DNV-GL ID# 2232. For Task 5, modern alloy steels A-537 and legacy A-537 (DNV-GL ID#1081) were used. Table 4-2 shows the chemical composition of the four modern alloy steels used with the respective DNV-GL identification number.

The welded plate that was used is shown in Figure 4-1. The weld can be observed in the middle of the plate. A magnified lateral picture of this plate is presented in Figure 4-2.

Table 4-2 Chemical Composition of Four Modern A-537 Steels

	Manufacturer (DNV-GL ID#)			
Element	**Dillinger (2311) wt.%**	**SSAB (2312) wt.%**	**Arcelor (2313) wt.%**	**Tata (2314) wt.%**
C	0.142	0.139	0.125	0.165
Mn	1.52	1.354	1.551	1.487
P	0.011	0.009	0.011	0.016
S	0.001	0.001	0.002	0.003
Si	0.367	0.222	0.275	0.378
Cu	0.025	0.189	0.104	0.018
Sn	0.001	0.006	0.007	0.002
Ni	0.047	0.116	0.078	0.020
Cr	0.038	0.082	0.094	0.024
Mo	0.023	0.063	0.028	0.009
Al	0.033	0.027	0.043	0.037
Nb	0.024	0.016	0.025	0.028
Fe	balance	balance	balance	balance

Figure 4-1 Carbon steel plate from AART128 Rail Car Steel welded in the center

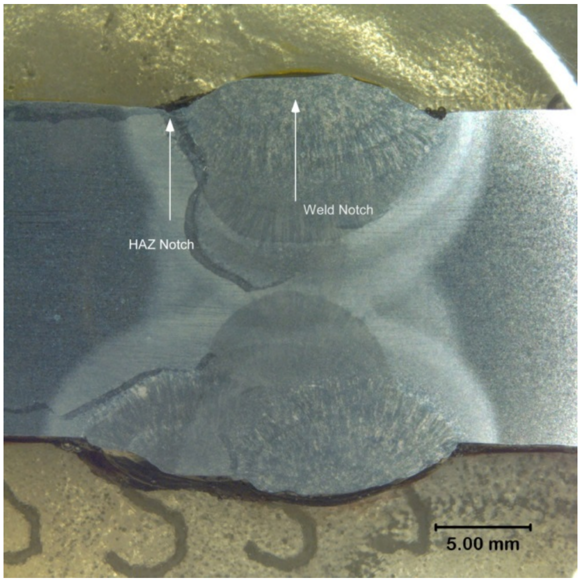


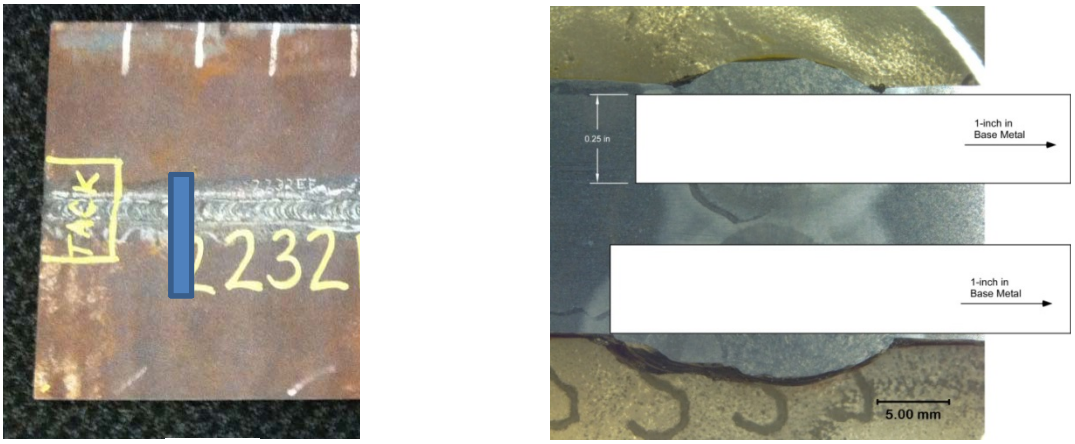
Figure 4-2 Lateral magnified picture of the carbon steel plate seen in Fig. 4-1. The picture shows the HAZ notch and weld notch.

Several welded plates were heat treated. The heat treatment temperatures were selected to simulate the microstructures that could have resulted due to a flame strengthening procedure performed in tank AY-102. This procedure was used during the construction of the primary liner of this DST to eliminate bulges in the carbon steel plates. The two recommended temperatures were 1200 °F (650 °C) and 1600 °F (871 °C). The temperature used and the procedure which the carbon steel was subjected to simulate flame strengthening is explained as follows:

1. 1200 °F (650 °C) for 1 hour followed by: a) water quench, b) slow cool.
    a. Recommended temperature for flame strengthening for this type of steel.
    b. The plates were probably not heated for more than a few minutes but a 1-hour heat treatment is recommended to allow an equilibrium microstructure. Since the actual time is unknown, it's probably best to use an equilibrated structure.
    c. Water quench in ice water is recommended. The procedure calls for the plate to be sprayed with water. In a cold month like January the water was likely very cold. An ice water quench is more severe than the plate being sprayed with water but it's a more controlled cooling rate.
    d. The slow cooling should be done by removing the plate/samples from the furnace and placing on a fire-brick.

2. 1600 °F (871 °C) for 1 hour followed by a) water quench, b) slow cool using the same water quenching and slow cooling methods as heat treatment no. 1.
    a. This temperature transforms a 0.2 % C steel fully to austenite so that the entire microstructure transforms to ferrite and iron-carbide upon cooling.

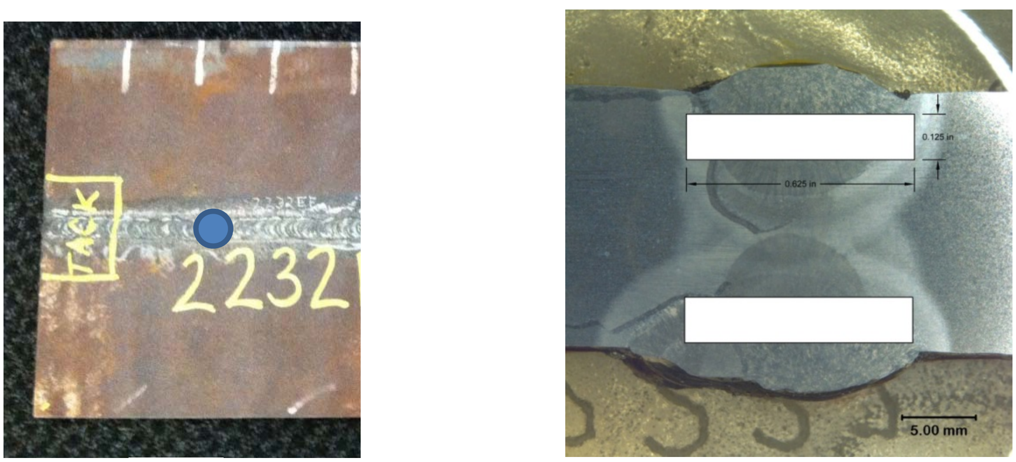
Carbon steel specimens were obtained from plates from the weld and heat affected zone (HAZ). Figure 4-3 shows pictures of the specimens selected for LAI and TI tests. Picture (a) shows the represented area that coupons were selected in the panel and picture (b) shows the selection of the specimens around the weld area and HAZ going to the base metal of about 0.25 inch thick and 1 inch long and 2 inches wide overlapping the entire weld cap.



(a) (b)

Figure 4-3 Pictures of carbon steel specimens for LAI and TI experiments: (a) representation of the selection of the specimens in the panel (blue rectangle) and (b) side view of the panel and representation of the selection in the weld and HAZ (white rectangles)

Figure 4-4 shows two pictures of the specimens selected for VSC tests. Picture (a) represents the area of the plate selected for the circular coupons and in picture (b) is seen the specimens selected in the weld area. There were two samples per location as close as possible to the surface.



(a) (b)

Figure 4-4 Pictures of carbon steel specimens for VSC experiments: (a) representation of the selection of the specimens in the panel (blue circle) and (b) side view of the panel and representation of the selection in the weld (white rectangles)

The coupons were received from DNV-GL and Metals Samples. A table in the next page (Table 4-3) explains the classification assigned at SRNL and a description of the treatment as-received of the sample.

Table 4-3 Classification of material obtained from DNV-GL

DNV-GL ID number	SRNL letter assignment	Description
2315	A	Welded DNV-GL# 2232 material heat treated to 1200 °F
2316	B	Welded DNV-GL# 2232 material heat treated to 1600 °F
2317	C	Welded DNV-GL# 2232 material with no heat treatment

Below are the experimental details and conditions in which the carbon steel was used and prepared for VS, LAI and TI, and electrochemical corrosion testing.

4.1 Vapor Space Corrosion Testing

4.1.1 *Materials*

Circular coupons were received from DNV-GL and Metal Samples for the testing. All the coupons were 0.625 inch diameter with different thicknesses and polished to a 600 grit finish. DNV-GL sent 36 coupons with a thickness of 0.125 inch and Metal Samples sent 36 coupons with a thickness of 0.335 inch. The coupons from DNV-GL were delivered unidentified and they were engraved prior to using them. The coupons were mounted using a two part clear epoxy solution (EpoKwick® from Buehler) so that one face of the coupon was exposed. In the plastic disposable mount, a wire was placed in a lateral position to be able to hang the coupons with no connection with the coupon. Excess epoxy mixture was used with a wood stick to cover around the edges of the disk to prevent crevice corrosion. For FY14, clear nail polish was used and it was shown that it did not prevent crevice corrosion and showed signs of disintegration during time [8]. Different colored wires were used to represent the different heat treatments that the steel was subjected. Table 4-4 describes the color of the wire and the SRNL letter assignment used depending on the DNV-GL numbered material.

Table 4-4 Color and SRNL letter assignment for carbon steel specimens

SRNL letter assignment	Wire color
A	**blue**
B	**purple**
C	**black**

Prior to use the coupons they were rinsed with deionized water and ethanol and blow dried with air. Pictures of coupons with the different colored wire can be observed in Figure 4-5. It can also be observed the excess epoxy addition around the edges of the coupon after it was mounted.

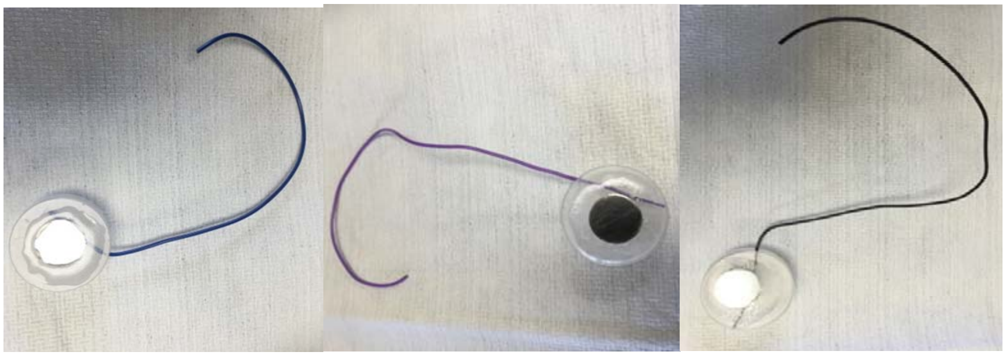


Figure 4-5 Coupon mounted in epoxy cold mount with wire

Twelve coupons were suspended in stainless steel rings at different locations welded to a stainless steel rod as shown in Figure 4-6. Three coupons were added at the top and middle location of the rod and six at the bottom.

Figure 4-6 Picture of the rod with three coupons hanged at the high and intermediate location and six coupons at the low location

4.1.2 *Simulants*

VS simulants compositions for each vessel are described in Appendix A. Test conditions for each vessel are shown in Table 4-5.

Table 4-5 Test conditions for VSC testing

Vessel	Initial pH	Ammonia gas concentration in Air (ppm)	Temperature (°C)
1	12	50	40
3	12	550	40
5	~10	0	45
6	~10	0	45
7	7.6	0	45
8	7.6	0	45

In general, six vessels were used. The first two vessels (Vessels 1 and 3) had a composition representing the new SCC control limits which is the ratio of nitrite/nitrate of 0.15. The low nitrate simulant was selected for a representation of a borderline condition of a low nitrate concentration. The pH of the simulant was selected as 12 to be slightly above the minimum requirement of 11. The composition of the minor constituents in the simulant is consistent with values from samples of the waste supernates that were utilized during previous testing [4],[8] and it is described in Table 4-6. Ammonia gas was humidified with the respective simulant and flowed through the vessels at 50 and 550 ppm for Vessels 1 and 3, respectively.

Table 4-6 Chemical composition of the low nitrate simulant

Chemical composition (M)							
$NaNO_2$	$NaNO_3$	NaCl	NaF	$Na2SO_4$	Na_2CO_3	Na_3PO_4	$Na_2Al2O_3.3H_2O$
0.06	0.4	0.01	0.003	0.005	0.1	0.0005	0.0002

For the next four vessels (Vessels 5, 6, 7 and 8), building air was humidified with the respective simulant for that vessel. The simulants for Vessels 5 and 6 corresponded to a simulant created based on thermodynamic results provided by the TIEP. Several formulations were prepared depending on evaporation, concentration of CO_2 and pH. From these, two formulations were selected to study VSC and are described in Table 4-7.

Table 4-7 Refractory formulations used to study VSC

Refractory formulations	pH	Temperature (°C)	Description
R-9	10.06	45	Interstitial liquid, evaporation to 0.135 H_2O, CO_2
R-12	10.32	45	Supernatant, evaporation to 0.142 H_2O, CO_2

The remaining two vessels, Vessels 7 and 8 had a chemical composition representing the LDP residue and GW found close to the secondary liner in the tank AY-102, respectively.

4.1.3 *Testing Apparatus*

The VSC apparatus is shown in Figure 4-7. Eight glass columns were prepared by the SRNL glass shop for FY14 testing and six of them were reused this year. These columns are fixed with holding rings that were mounted on an aluminum frame inside a walk-in hood. The columns have dimensions of 1 m by 15 cm and consist of a jacketed glass vessel connected to a glass tube and closed at the top with a glass cap. 1 Liter of simulant was added to each vessel and the temperature was monitored with a temperature reader (Omega). The gas cylinders provided ammonia gas (50 and 550 ppm) to two of these vessels (Vessel 1 and 3). The cylinders were connected to a mass flow controller and a flowmeter at each gas concentration to maintain a flow of 5 sccm. Building air was used for the remaining vessels and was diverted to four different flowmeters to supply constant air at 5 sccm. Vessel 1 and 3 (from right to left) were connected in parallel to a water circulator that maintained the simulant temperature at 40 °C. The last four vessels (from right to left) were connected to another water circulator in parallel to maintain a simulant temperature of 45°C. The ammonia gas and building air was bubbled through a bottle filled with the corresponding simulant to humidify the gas before it entered the column.

The rods containing the coupons were placed inside the vessels. They represent different levels above the simulant. These levels are described as follows:

Level 3: This set of coupons was not exposed to the solution prior to testing. The coupons were suspended approximately 36 inches above the simulant. This level is representative of a vapor space region that is only exposed to the humidified air, the ammonia (if applicable), and any volatile species from the solution.

Level 2: The coupons were dipped in simulant for five minutes prior to test. The coupons were hung at the middle fixed ring. These coupons were approximately 18 inches above the liquid. This level is representative of a vapor space region of the tank that at one time was exposed to waste, but now has infrequent or no contact with the waste. However, this region is exposed to the humidified air and/or the ammonia gas.

Level 1: The coupons were dipped in simulant for five minutes prior to test. The coupons were hung at the bottom fixed ring. These coupons were suspended approximately 1 inch above the liquid level of the simulant. Once every two weeks the coupons were lowered to the solution to be dipped in the simulant for 5 minutes. This level is representative of a vapor space region of the tank that experiences periodic wetting/drying. This sequence could occur due to: a) waste transfers into and out of the tank, b) splashing due to flushing operations, and/or c) solution “creep” above the liquid air interface.

Testing of the coupons in vapor space environment was performed for four months with specimens at level 1 taken at two months periods (i.e., 3 coupons for a total of 18). For Level 3 and 2 the specimens remained at the four months period. Coupons were removed from the epoxy cold mount using a special tool and cleaned using ASTM G1 Clark's solution [20] to record weight losses.

Figure 4-7 Picture of the Vapor Space Corrosion setup inside the walk-in hood

4.2 <u>Liquid Air Interface and Total Immersion Corrosion Testing</u>

4.2.1 *Materials*

Twenty four rectangular carbon steel coupons, fabricated from the rail car steel, were obtained from DNV-GL that were 1 inch by 2 inches and 0.25 inch thick. Twelve of these coupons were positioned in solution so that approximately 65% of the coupon was immersed; the remaining coupons were immersed completely. Prior to the test, the surface was polished on 600 grit paper and rinsed with distilled water and acetone. Figure 4-8 shows an example of the coupon. A stainless steel rod was used to connect to the coupon and fixed it in place for long term testing. The stainless steel rod was insulated with Teflon tape to prevent vapor space contact with the simulant.

Figure 4-8 Rectangular coupon for LAI test

4.2.2 *Simulants*

LAI corrosion tests were conducted using simulants with different chemical compositions. A total of 18 containers were utilized consisting of 6 different formulations of simulants. The first 12 containers have simulant compositions shown in Table 4-8. A detailed chemical composition for all containers can be found in Appendix C.

Table 4-8 Nitrate and nitrite concentrations for LAI corrosion test simulants.

Solutions	Nitrate (M)	Nitrite (M)	Nitrite/Nitrate Ratio	pH	Comments
1	0.1	0.05	0.5	12	Dilute solution; Minimum nitrite allowed by new SCC requirement; Ratio is greater than that required by new SCC limits, but less than that required by Zapp's law [21]
2	0.5	0.075	0.15	12	At approximately this concentration of nitrate, Hoffman observed that the addition of more nitrite was not necessarily beneficial [22]; Minimum nitrite/nitrate ratio for new SCC limit.
3	0.5	0.83	1.66	12	Zapp's law minimum required nitrite to nitrate ratio.
4	1	1.66	1.66	12	Zapp's law minimum required nitrite to nitrate ratio.

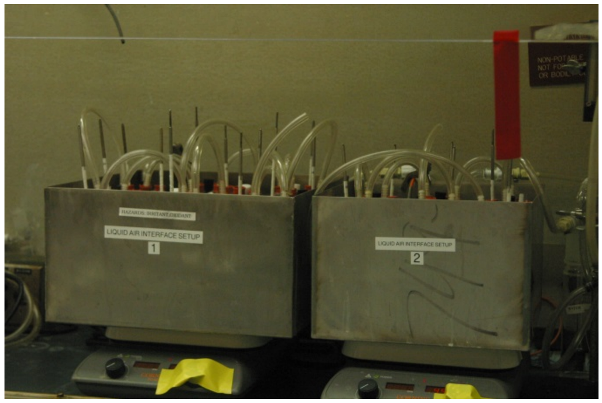
Corrosion tests were also performed with completely immersed coupons in LDP and ground water simulants, which simulated the environment on the exterior of AY-102 secondary liner.

4.2.3 *Testing Apparatus*

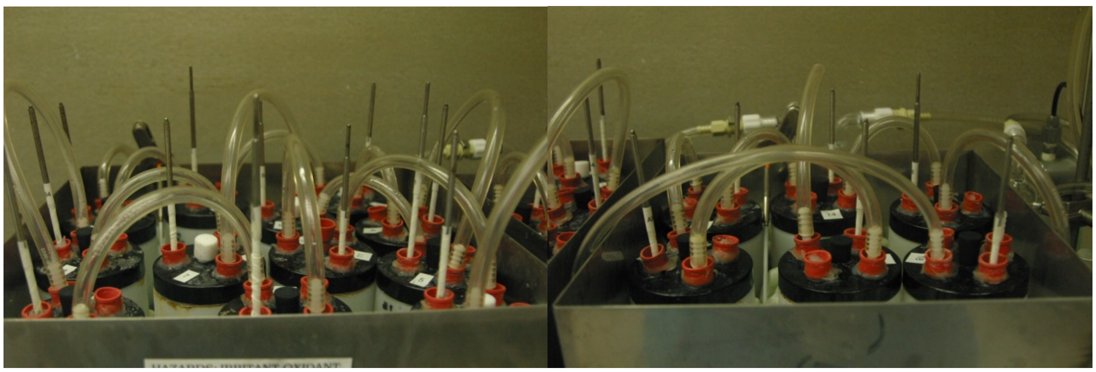
The testing for this task was performed in 1 Liter polycarbonate bottles, similar in design as our testing in FY14. The caps were modified as observed in Figure 4-9. Orange rubber stoppers were placed in four of the holes. Two connectors were attached to flexible Tygon tubing to provide an inlet and outlet flow of air and the other two stabilized the stainless steel rods that held the rectangular coupons in position (white Teflon tape covered rods). The stoppers were sealed with silicone to prevent air leakage. A hole in the middle was used to provide access to a pH probe, a thermocouple, and a reference electrode. In the picture this hole has a black rubber stopper.

Figure 4-9 Modified cap of containers for LAI corrosion studies

Twelve containers were placed in a water bath at 40 °C and eight containers were placed in a smaller bath at 45 °C. Pictures of the two water baths used are shown in Figure 4-10. The water bath consists of a stainless steel box on top of a hotplate with water at the level of the simulant inside the container. The temperature of the bath was controlled by placing the hotplate thermocouple into the water surrounding the plastic containers. These containers were connected in series with Tygon tubing to provide the flow of air from a gas humidifier that was connected to a flowmeter for a flow rate of 5 sccm. The evaporation of water from the bath was minimized by placing packaging styrofoam pellets above the water.



(a)



(b)

Figure 4-10 LAI corrosion setup in hood showing (a) the two baths on top of a hot plate and (b) showing the contents of the two baths

In each container 500 mL of the specified simulant was added. The rods that hold the coupons were lowered to reach the desired position within the liquid. The containers were placed in the bath and water was added to reach similar level as the liquid inside the container. This level inside was marked outside the container to account for losses during testing. Water was added periodically to the bath to maintain the same level. Make-up distilled water was added in some instances to the containers to also maintain the LAI level, although on a less frequent basis.

At the beginning of testing pH, temperature and OCP was measured. The temperature, pH and OCP in each container was taken daily during working days. The coupons were maintained at these conditions for four months. A coupon was removed after two month interval from the containers with two coupons (containers 13 to 18).

At the end of testing the coupons were removed and cleaned using ASTM G1 Clark's solution [20] and weight losses were recorded. Table 4-9 shows a summary of the conditions for each container.

Table 4-9 LAI conditions and immersion percent of each coupon

Container	Solution	Temperature (°C)	Simulant	Coupon condition	Immersion percent
1	1	40	Different ratio NO_2/NO_3	A	65
2	2	40	Different ratio NO_2/NO_3	A	65
3	3	40	Different ratio NO_2/NO_3	A	65
4	4	40	Different ratio NO_2/NO_3	A	65
5	1	40	Different ratio NO_2/NO_3	B	65
6	2	40	Different ratio NO_2/NO_3	B	65
7	3	40	Different ratio NO_2/NO_3	B	65
8	4	40	Different ratio NO_2/NO_3	B	65
9	1	40	Different ratio NO_2/NO_3	C	65
10	2	40	Different ratio NO_2/NO_3	C	65
11	3	40	Different ratio NO_2/NO_3	C	65
12	4	40	Different ratio NO_2/NO_3	C	65
13	5	45	Leak Detection Pit (LDP)	A	100
14	5	45	Leak Detection Pit (LDP)	B	100
15	5	45	Leak Detection Pit (LDP)	C	100
16	6	45	Ground Water (GW)	A	100
17	6	45	Ground Water (GW)	B	100
18	6	45	Ground Water (GW)	C	100

4.3 Electrochemical Testing of Simulants

4.3.1 *Material sample*

Carbon steel in the form of “bullets” with dimensions 0.188 inch diameter and 1.25 inches long (Metal Samples EL-400) were used for the electrochemical testing. Before testing, a drill was used to polish the sample to a 600-grit finish. The electrodes were examined with a stereomicroscope and in some cases visually for any defect and to ensure that the sample had a homogeneous surface. Then they were rinsed with distilled water and acetone. Figure 4-11 shows a picture of the sample after being polished and rinsed. It shows the surface of the shank and nose of the bullet. The bullet was attached to a stainless steel rod protected by a glass holder. A Teflon fixture was used to prevent liquid contact with the stainless steel rod and ensure electrical isolation.

The rail car steel was utilized for tasks 3 and 4 (see Table 4-1). Four modern A-537 steels, provided by DNV-GL, were tested for task 5. The steels were fabricated into the bullets for testing.

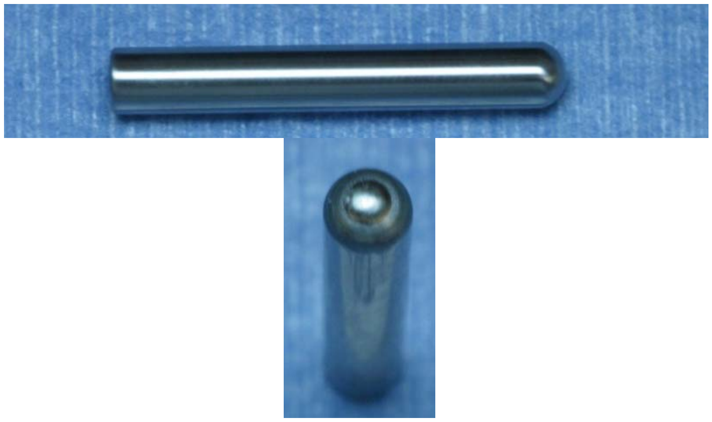


Figure 4-11 Side picture of the bullet (top) and frontal top picture of the bullet (bottom)

4.3.2 *Simulants*

Simulants were prepared for three tasks (Task 3, Task 4 and Task 5) from the task activities. For Task 3, simulants were created based on the Argentina work to be repeated using the new testing protocol a second set of dilute waste chemistry solutions that had nitrate concentrations between 0.5 to 2.0 M. Table 4-10 describes the chemical compositions of the selected experiments. The first 18 tests utilized simulants based on the Argentina work. All experiments were performed at 40°C.

For Task 4 simulants were made based on waste buffering from tank AN-102 waste. The chemical composition of some of the constituents of the original experimentation is presented in Table 4-11. All testing was performed at 40 °C. Task 5 used two solutions for testing, which are given in Table 4-12. The tests were carried out at room temperature, 25 °C and a pH of 10.

Table 4-10 Testing compositions for comparison of Argentina Results and Dilute Solutions to standard testing protocol

Test	Concentration of species (M)									
	NaOH	Nitrite	Citrate	Na_2CrO_4	Nitrate	NaCl	NaF	Na_2SO_4	Na_2CO_3	Na_3PO_4
1	0	0.5	0.6	0.0001	0.01	0.01	0.003	0.1	0.2	0.0005
2	0	0.5	0.04	0.1	0.01	0.01	0.02	0.005	0.2	0.05
3	0	0.02	0.04	0.1	0.01	0.06	0.02	0.1	0.02	0.005
4	0	0.02	0.04	0.1	0.01	0.4	0.003	0.005	0.02	0.0005
5	0	0.5	0.6	0.0001	0.01	0.4	0.003	0.1	0.2	0.05
6	0	0.1	0.6	0.1	0.01	0.4	0.05	0.1	0.02	0.0005
7	0.01	0.1	0.6	0.1	0.01	0.06	0.003	0.1	0.02	0.05
8	0.01	0.1	0.6	0.005	0.7	0.06	0.05	0.005	0.2	0.05
9	0.01	0.02	0.04	0.1	0.7	0.06	0.05	0.1	0.2	0.05
10	0.01	0.5	0.6	0.05	0.1	0.4	0.02	0.005	0.02	0.0005
11	0.01	0.1	0.04	0.05	0.7	0.01	0.003	0.005	0.02	0.0005
12	0.1	0.02	0.04	0.05	0.1	0.01	0.05	0.005	0.02	0.05
13	0.1	0.5	0.6	0.05	0.1	0.01	0.02	0.1	0.02	0.005
14	0.1	0.1	0.6	0.05	0.1	0.06	0.05	0.005	0.2	0.05
15	0.1	0.02	0.04	0.05	0.1	0.4	0.003	0.1	0.2	0.0005
16	0.1	0.5	0.6	0.1	0.1	0.4	0.003	0.005	0.02	0.0005
17	0.1	0.02	0.04	0.005	0.1	0.4	0.02	0.1	0.02	0.05
18	0.1	0.5	0.6	0.1	0.7	0.4	0.02	0.1	0.2	0.05
19	0.01	0.1	0.04	-	0.5	0.06	0.003	0.005	0.02	0.01
20	0.01	0.5	0.04	-	0.5	0.06	0.01	0.1	0.2	0.005
21	0.01	1	0.04	-	0.5	0.4	0.003	0.005	0.2	0.005
22	0.01	0.5	0.04	-	1	0.06	0.01	0.005	0.02	0.01
23	0.01	1	0.04	-	1	0.06	0.003	0.1	0.02	0.005
24	0.01	1.5	0.04	-	1	0.4	0.01	0.1	0.2	0.01
25	0.01	1	0.04	-	1.5	0.06	0.003	0.1	0.2	0.005
26	0.01	1.5	0.04	-	1.5	0.4	0.003	0.005	0.02	0.01
27	0.01	2	0.04	-	1.5	0.4	0.01	0.005	0.2	0.01
28	0.01	1	0.04	-	2	0.06	0.01	0.1	0.2	0.005
29	0.01	1.5	0.04	-	2	0.4	0.01	0.005	0.02	0.01
30	0.01	2	0.04	-	2	0.06	0.003	0.1	0.02	0.005

Table 4-11 Original table of testing and chemical composition for Nitrate, Nitrite and Hydroxide

Test	Nitrate (M)	Nitrite (M)	Hydroxide (M)
1	1.1	0.5	0.01
2	1.1	1	0.01
3	1.1	1.5	0.01
4	1.1	0.5	0.05
5	1.1	1	0.05
6	1.1	1.5	0.05
7	3	0.5	0.01
8	3	1	0.01
9	3	1.5	0.01
10	3	0.5	0.05
11	3	1	0.05
12	3	1.5	0.05
13	5.5	0.5	0.01
14	5.5	1	0.01
15	5.5	1.5	0.01
16	5.5	0.5	0.05
17	5.5	1	0.05
18	5.5	1.5	0.05

Table 4-12 Simulant compositions for testing different heats of carbon steel

Component	HTWOS A	HTWOS B
Sodium Aluminate	1.06E-03	1.06E-03
Sodium Chromate	1.75E-03	1.75E-03
Potassium Nitrate	2.94E-03	2.94E-03
Ammonium Chloride	2.68E-02	2.68E-02
Sodium Hydroxide	2.15E-02	2.15E-02
Sodium Bicarbonate	5.40E-02	0.00E+00
Sodium Carbonate	2.60E-02	0.00E+00
Sodium Chloride	-	-
Sodium Fluoride	7.64E-02	7.64E-02
Sodium Nitrate	8.63E-02	8.63E-02
Sodium Nitrite	2.32E-04	2.32E-04
Sodium Sulfate	2.44E-02	2.44E-02
Sodium Phosphate	2.17E-04	2.17E-04
pH	10	10

4.3.3 *Testing Apparatus*

Approximately 700 mL of simulant was added to a cell made by the SRNL glass shop that is similar to the cell for corrosion studies designed by Princeton Applied Research. Two carbon graphite rods served as the counter electrode. A saturated calomel electrode (SCE) was used as the reference electrode. Prior to each test, the electrode was checked against a standard before testing (a SCE in 1 M KCl solution not used for testing). The SCE was placed in a bridge containing 0.1 $NaNO_3$ solution. The cell was placed on top of a hotplate with temperature control. REF600 (Gamry) and VMP3 (Bio-Logic) potentiostats were used in this study and prior of using them ASTM G5 [23] was performed for quality assurance. ASTM G5 protocols were also run at the end of testing. The standardized pitting protocol was used to gather the data. The open circuit potential (OCP) was measured for two hours to ensure equilibration of the carbon steel in solution. The cyclic potentiodynamic polarization (CPP) test was conducted by applying a cyclic potential ramp from -50 mV vs. OCP up to a vertex threshold current of 1 mA/cm^2 at a scan rate of 0.167 mV/s. The potential was finally returned back to the OCP to complete the test.

5.0 Results and Discussion

Appendix B and D shows the pictures of samples after exposure for Task 1 and 2, respectively. For Task 3, 4 and 5 electrochemical results and/or pictures of the coupons after testing are shown in Appendix F, G and H, respectively. For the presentation and discussion of results, the activities were separated into sections corresponding to the particular tank, except for the pitting corrosion results for the Argentina results using the standard testing protocol (Task 3) and material selection (Task 5).

5.1 Secondary Wall of Tank AY-102 Corrosion Studies

Solutions consisting of simulants from the LDP and ground water near the exterior of the secondary liner, and simulated wastes in contact with the refractory liner between the primary and secondary liner of Tank AY-102 were prepared for the corrosion studies. During FY14, LAI, TI and VSC were performed to assess the corrosion behavior of carbon steel to LDP and GW simulants. Similar corrosion rates for LAI and TI were measured [8]. For FY15, only TI and VSC tests were performed using LDP and GW simulants and only VSC tests were performed using refractory waste simulants. The results are shown in the following subsections.

5.1.1 *Total Immersion tests*

Long term immersion tests were used to determine corrosion susceptibility of welded carbon steels with different heat treatments. Photographs of the coupons after two and four months periods are shown in Figure 5-1 for LDP and Figure 5-2 for GW.

General attack occurred on the surfaces of all coupons. However, more corrosion was observed on the coupons exposed to the GW simulant than the LDP simulant. Table 5-1 shows the weight loss and corrosion rates for all the samples after exposures for two and four months. As seen in the table, there were clearly several changes in weight loss of all samples depending on the simulant and exposure time. For coupons exposed to the LDP simulant from two to four months, the corrosion rates decreased by a factor of 2 for A and B and a factor of 3 for C. For GW simulant, the corrosion rate was similar for B and C and it decreased by a factor of 2 for A. The welded and HAZ carbon steel samples have different corrosion rates from samples exposed in LDP and GW. This is significantly different from the corrosion rates measured for the base legacy carbon steel (i.e. no welding or heat treatment) obtained in FY14. The corrosion rates from completely immersed coupons maintained corrosion rates about 10 mpy after two and four months for LDP and GW simulant [8].

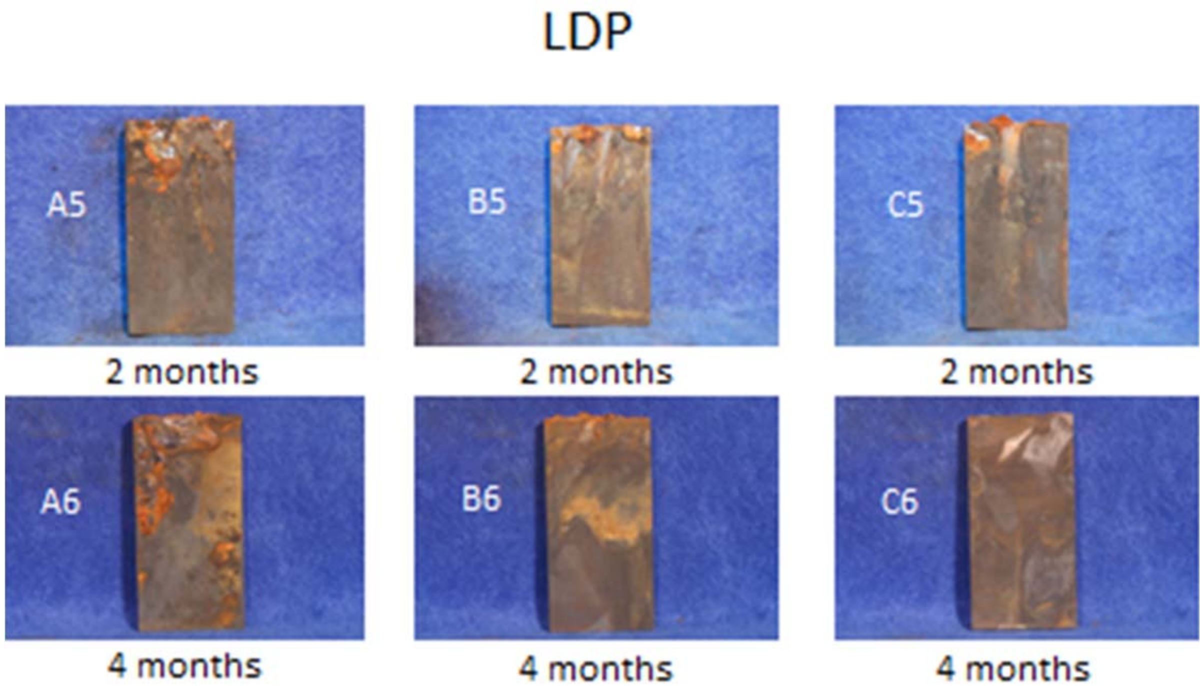


Figure 5-1 Coupons from LAI and TI corrosion test using LDP simulant

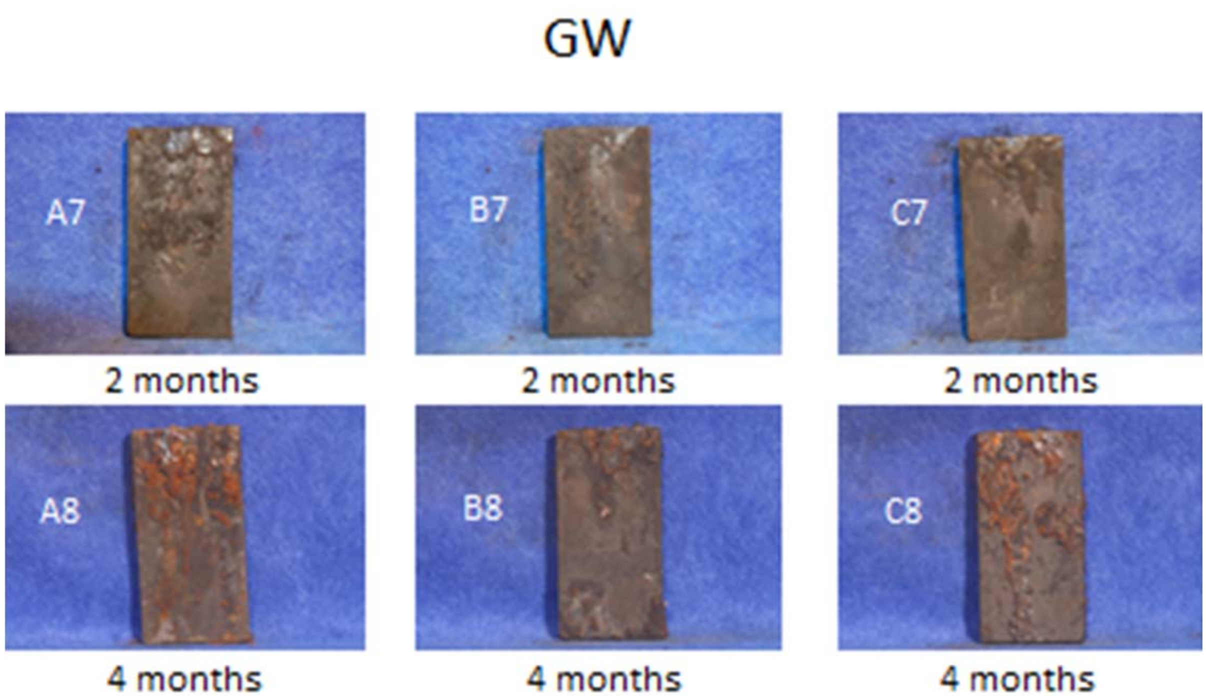


Figure 5-2 Coupons from LAI and TI corrosion test using GW simulant

Table 5-1 Weight losses and corrosion rates for carbon steel coupons exposed to LDP and GW simulants

Solutions	Months Exposure - Total Immersion					
	Two months			Four months		
	Coupon name	weight loss (g)	Corrosion rate (mpy)	Coupon name	weight loss (g)	Corrosion rate (mpy)
5 (LDP)	A5	0.7143	6.57	A6	0.7314	3.37
5 (LDP)	B5	0.8959	8.25	B6	0.9733	4.48
5 (LDP)	C5	0.5983	5.51	C6	0.1827	0.84
6 (GW)	A7	1.0003	9.21	A8	0.9733	4.48
6 (GW)	B7	1.0984	10.11	B8	1.8129	8.34
6 (GW)	C7	1.1883	10.94	C8	2.0207	9.30

Figure 5-3 shows OCP vs. time for (a) LDP and (b) GW. For all cases, the OCP started between -690 to -704 mV vs. Ag/AgCl after a period of stabilization and then proceeded to more noble values. For the LDP simulant, the stabilization of the OCP in solution took several days and the potential started to increase at an exponential rate and then stabilized for the remainder of the test. In contrast, OCP values in the GW simulant started at low potentials and then gradually continued to increase and did not reach a plateau after four months. This is similar to what it was observed for the base carbon steel in FY14 [8].

Comparing the OCP data with the weight loss and corrosion rates, some points can be considered. For LDP simulants, conditions B and C have similar response and reached similar stabilization potential just after 100 hours and, for condition A, OCP stabilization started after 750 hours. There was an exception in the stabilization potential for C6 in which it reached pseudo-stabilization after 100 hours but continued to increase the OCP slowly and reached complete stabilization after 1000 hours to positive OCP potentials. The high noble potentials may indicate that a passive layer has formed during the test and this is corroborated by the low general corrosion rate of less than 1 mpy (Table 5-1). The more active potentials observed during the first 1500 hours (two months) of testing may also explain why the corrosion rate was higher during the first two months than it was during the final two months of testing.

For the base metal tests performed in the same simulants, the OCP started to stabilize after 1100 hours and reached similar potentials as the coupons studied in FY15 [8]. For GW simulants, all three conditions showed similar OCP response which provided an active region for the duration of the test. For the base metal, the potential continued to stabilize during the four months, but the potential stayed below -600 mV for the first 1000 hours [8]. Comparing with results for FY14, it seems also that the as-received base metal continues to corrode at a similar rate during the four months and the OCP transients showed more active potentials and longer stabilization periods than the heat treated and welded materials [8].

An interesting discovery was that the pH increased at an accelerated rate for the tests in the GW simulant. This accelerated rate was not observed for the LDP simulant. Figure 5-4 shows the pH as a function of time for this simulant. The pH went from approximately 7.6 to about 10.65 for the highest case. An XRD was performed of the corrosion products that settled at the bottom of the container to determine compounds that may influence the pH change over time. However, the amorphous carbon in the sample prevented the spectrum from showing any crystalline phases (results not shown). Generally, there was no change in corrosion rate or OCP stabilization depending on the heat treatment for the welded metal. However, the pH changes for the base metal were consistent for LDP and GW simulant for the duration of the test [8].

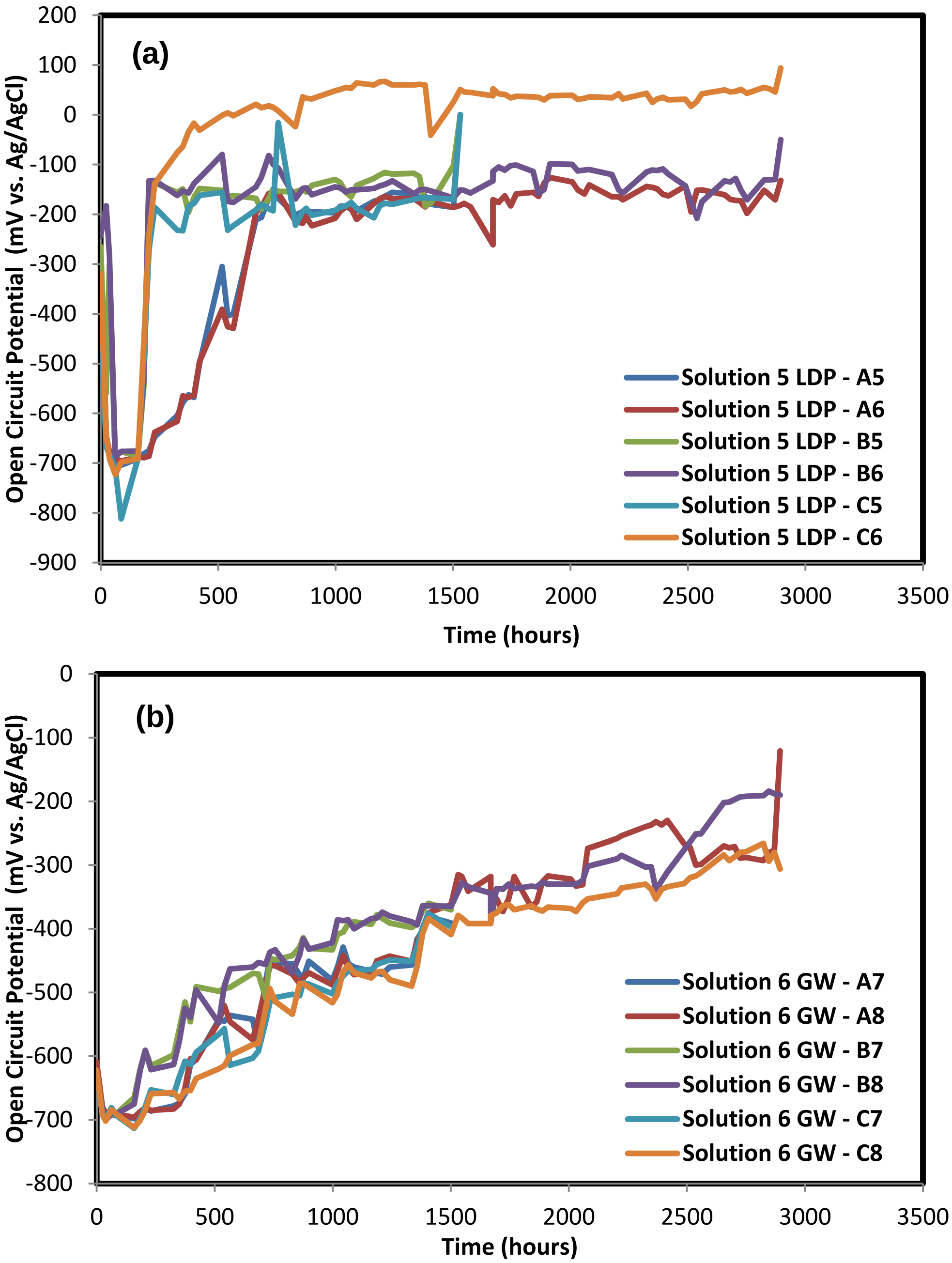


Figure 5-3 OCP vs. time of carbon steel coupons exposed to (a) LDP and (b) GW simulants for four months

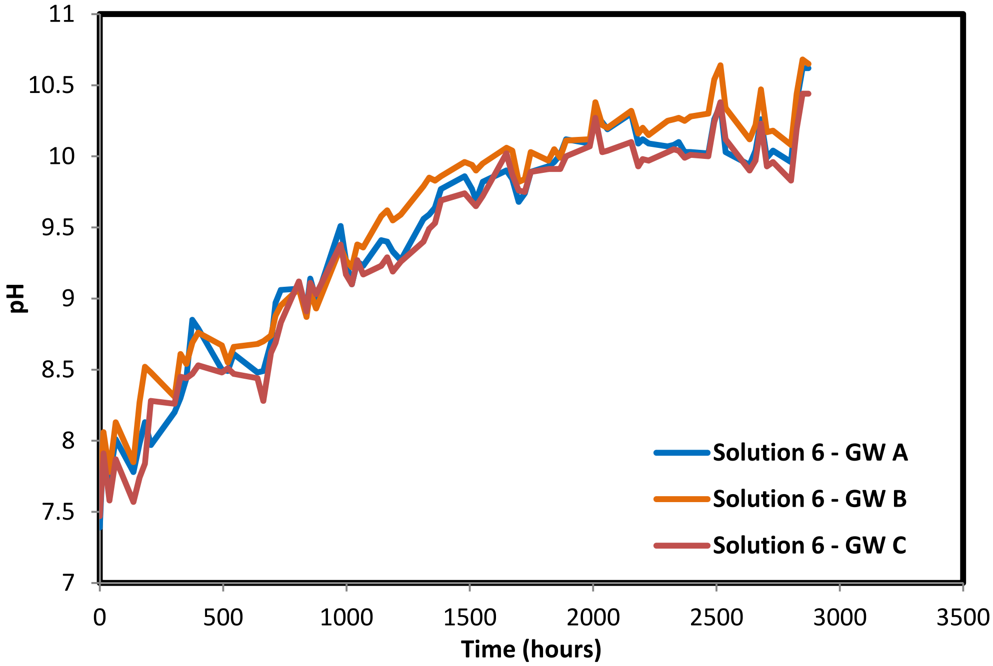


Figure 5-4 pH vs. time of carbon steel coupons exposed to GW simulants for four months

Pit depths and diameters were measured using a laser scanning confocal microscope (LSCM) and results are displayed in Table 5-2. For all coupons there was strong general corrosion attack over the entire sample with some samples that had more level of attack than others. There were a few instances for LDP coupons (B6 and C6) with localized corrosion areas that had a stronger attack. Measuring the pit depth and diameter, C6 and B6 had very small pit depths of 0.4 to 1.5 mils and diameters of 0.6 to 1.5 mils in most of the surface except for the low percentage in which the sample was subjected to more strong corrosion attack. Mostly, the attack was more severe for GW samples than LDP samples as expected from the calculated corrosion rates (Table 5-1). However, overall there was not a distinction between conditions A, B and C and distinctive corrosion patterns in or near the weld zone from the rest of the metal.

Table 5-2 Pitting diameter and depth range of solutions from LDP and GW simulants. Percentages were obtained by a qualitative assessment.

Solution	Coupon name	Time exposed (months)	diameter range (mils)	depth range (mils)	Remarks
5 (LDP)	A5	2	1.2-21.4	0.9-4.1	GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	A6	4	1.1-27.0	1.7-15.2	GA observed at the top and bottom areas and minor GA everywhere else. No distinction of corrosion attack in the weld area from the rest of the coupon.
5 (LDP)	B5	2	0.9-3.8	0.4-2.3	GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	B6	4	1.0-15.6	0.6-3.7	Strong GA observed at the top area and small areas with less than 5% of coupon. GA observed in all sample. No distinction of corrosion attack in the weld area from the rest of the coupon.
5 (LDP)	C5	2	0.8-3.4	0.9-5.4	Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	C6	4	0.7-4.1	1.1-3.6	Strong GA observed at the top area and small areas with less than 20% of coupon. GA observed in all sample. No distinction of corrosion attack in the weld area from the rest of the coupon.
6 (GW)	A7	2	1.0-4.0	1.5-8.2	Very Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	A8	4	2.2-27.7	2.1-10.4	Very Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
6 (GW)	B7	2	1.0-7.8	1.0 - 6.5	Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	B8	4	1.7-20.5	0.9-12.7	Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
6 (GW)	C7	2	0.8-6.1	0.8-8.1	Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.
	C8	4	1.6-39.0	1.5-16.2	Strong GA with large and deep pits in all surface of the coupon were observed with no distinction in the weld area.

GA – General Attack

5.1.2 *Vapor space corrosion tests*

Vapor space corrosion testing using LDP and GW simulants was conducted for four months at three different levels. Coupons were removed after four months with coupons at the lower level (Level 1) also being removed after two months. Figure 5-5 and Figure 5-6 show pictures of the coupon after exposure of LDP (Vessel 7) and GW (Vessel 8) simulants.

In general terms, VSC was more significant on the coupons above the GW simulant (Vessel 8) than LDP simulant (Vessel 7) which is similar to what is what observed in FY14. This also correlates to what it was observed for TI tests in which the corrosion attack was worse for the GW coupons. Additionally, coupons at the low level (Level 1) have significantly more corrosion than the other levels, except some cases where coupons presented more localized corrosion at the other levels (i.e., A05, B05, B09 and A10). These samples may have been subjected to more condensation and no inhibition from the vapor phase, which could have made a more significant attack on the surface. No other VSC samples presented similar corrosion patterns from all the VSC testing. For samples at Level 1, LDP samples showed worse surface corrosion as time progresses from two to four months, unlike GW which showed similar VSC. The GW samples already developed a corrosion product film on the alloy surfaces before the end of the second month, and appeared to be maintained for the duration of the testing with no significant changes. This is similar to what was observed for the base metal in FY14 [8].

Table 5-3 shows the weight loss and corrosion rates for samples exposed to the VS using LDP and GW simulants. As seen in the table, this type of corrosion produces minimal changes in weight losses which accounted for less than 0.64 mpy at the highest corrosion rate. Corrosion rates obtained were higher for the samples previously identified to have more localized corrosion, since the weight loss from VSC is considerably small compared to other types of corrosion. Although using epoxy around the side of each coupon prevented crevice corrosion, there is not a direct correlation from the type of pre-treatment (i.e. welded and heat treated to different temperatures) to the degree of VSC that can occur. In general, it seems that VSC was more severe at samples at the GW simulant and at Level 1 which were subjected to constant wetting/drying periods by comparing to the corrosion rates globally.

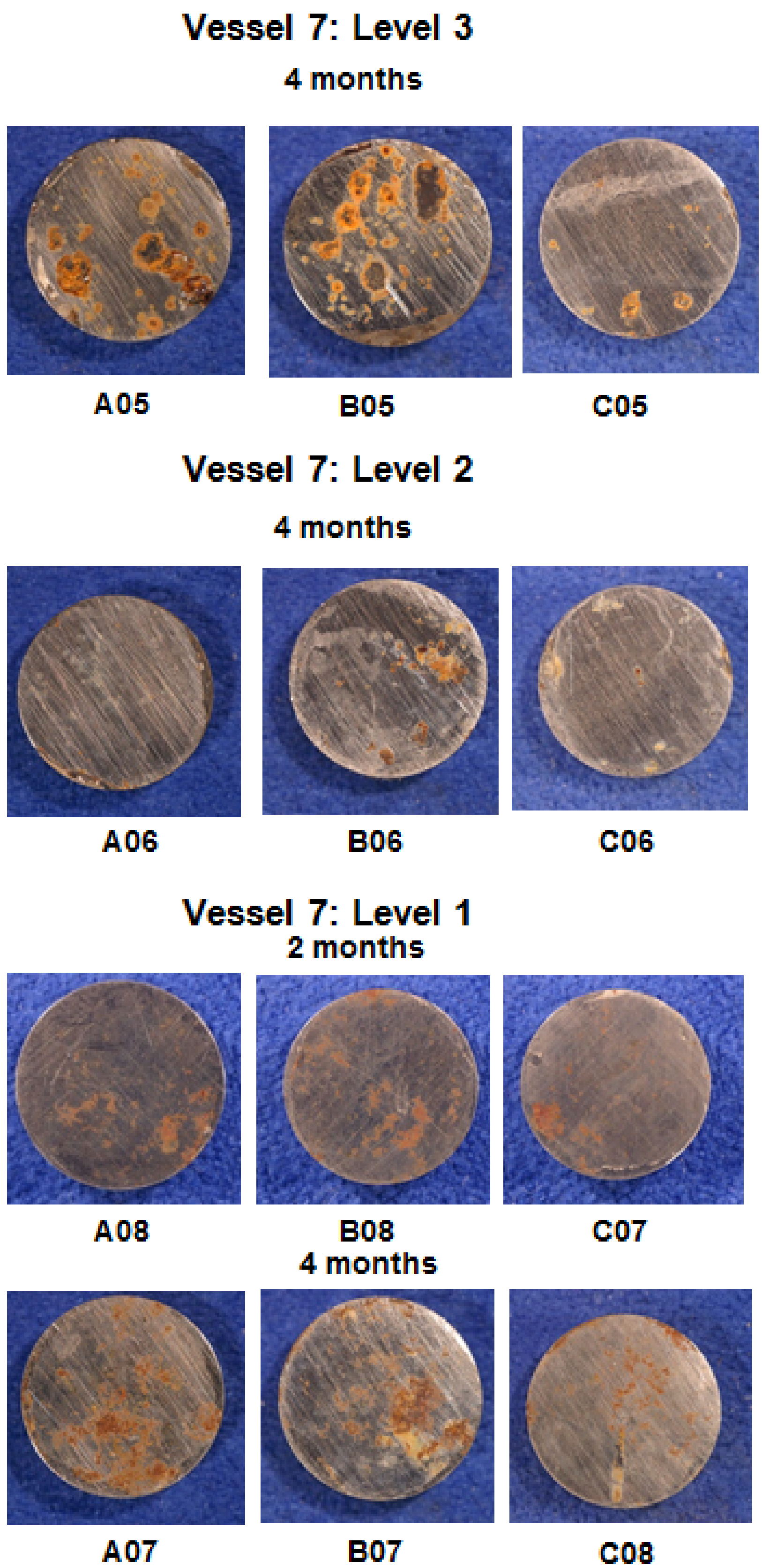


Figure 5-5 Pictures after VS exposure in simulant 7 at three different levels

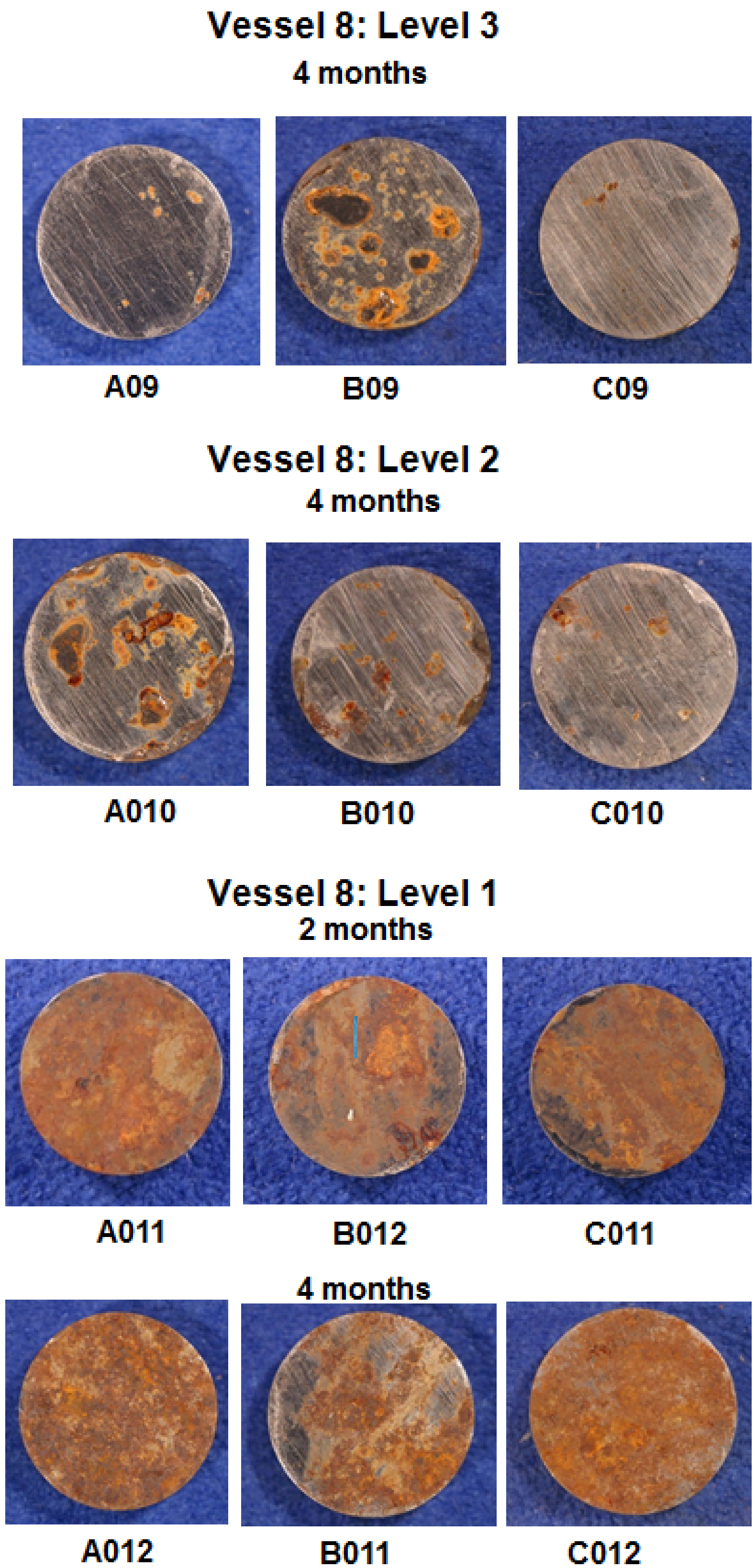


Figure 5-6 Pictures after VS exposure in simulant 8 at three different levels

Table 5-3 Weight losses of coupons at different levels in solutions 7 and 8

Vessel number	Coupon number	Level in vessel	Time exposure (month)	Weight loss (g)	Corrosion rate (mpy)
7	A05	High (Level3)	4 months	0.0068	0.56
	B05	High (Level3)	4 months	0.0065	0.54
	C05	High (Level3)	4 months	0.0022	0.18
	A06	Middle (Level 2)	4 months	0.0008	0.07
	B06	Middle (Level 2)	4 months	0.0002	0.02
	C06	Middle (Level 2)	4 months	0.0007	0.06
	A08	Low (Level 1)	2 months	0.0003	0.05
	A07	Low (Level 1)	4 months	0.0019	0.16
	B08	Low (Level 1)	2 months	0.0000	0.00
	B07	Low (Level 1)	4 months	0.0002	0.02
	C07	Low (Level 1)	2 months	0.0001	0.02
	C08	Low (Level 1)	4 months	0.0004	0.03
8	A09	High (Level3)	4 months	0.0009	0.07
	B09	High (Level3)	4 months	0.0077	0.64
	C09	High (Level3)	4 months	0.0005	0.04
	A010	Middle (Level 2)	4 months	0.0048	0.40
	B010	Middle (Level 2)	4 months	0.0009	0.07
	C010	Middle (Level 2)	4 months	0.0018	0.15
	A011	Low (Level 1)	2 months	0.0026	0.43
	A012	Low (Level 1)	4 months	0.0077	0.64
	B012	Low (Level 1)	2 months	0.0066	0.59
	B011	Low (Level 1)	4 months	0.0022	0.18
	C011	Low (Level 1)	2 months	0.0040	0.66
	C012	Low (Level 1)	4 months	0.0050	0.41

VSC testing above refractory simulants was conducted for fourth months at three levels; with coupons at the lower level being removed after two months and coupons being removed at all levels after four months. Pictures of the coupons after cold mounting removal are shown in Figure 5-7. Vessel 5 corresponded to the coupons exposed in vapor space using R-9 simulant and Vessel 6 corresponded to the coupons exposed in vapor space using simulant R-12. As seen in the pictures, there is very minor if any VSC in any of the coupons. The high nitrite in these solutions can provide corrosion inhibition when carbon steel is exposed in a liquid simulant and it seems it acted as a corrosion inhibitor as a vapor. Weight losses and corrosion rates reported in Table 5-4 show that there was minimal or no weight losses.

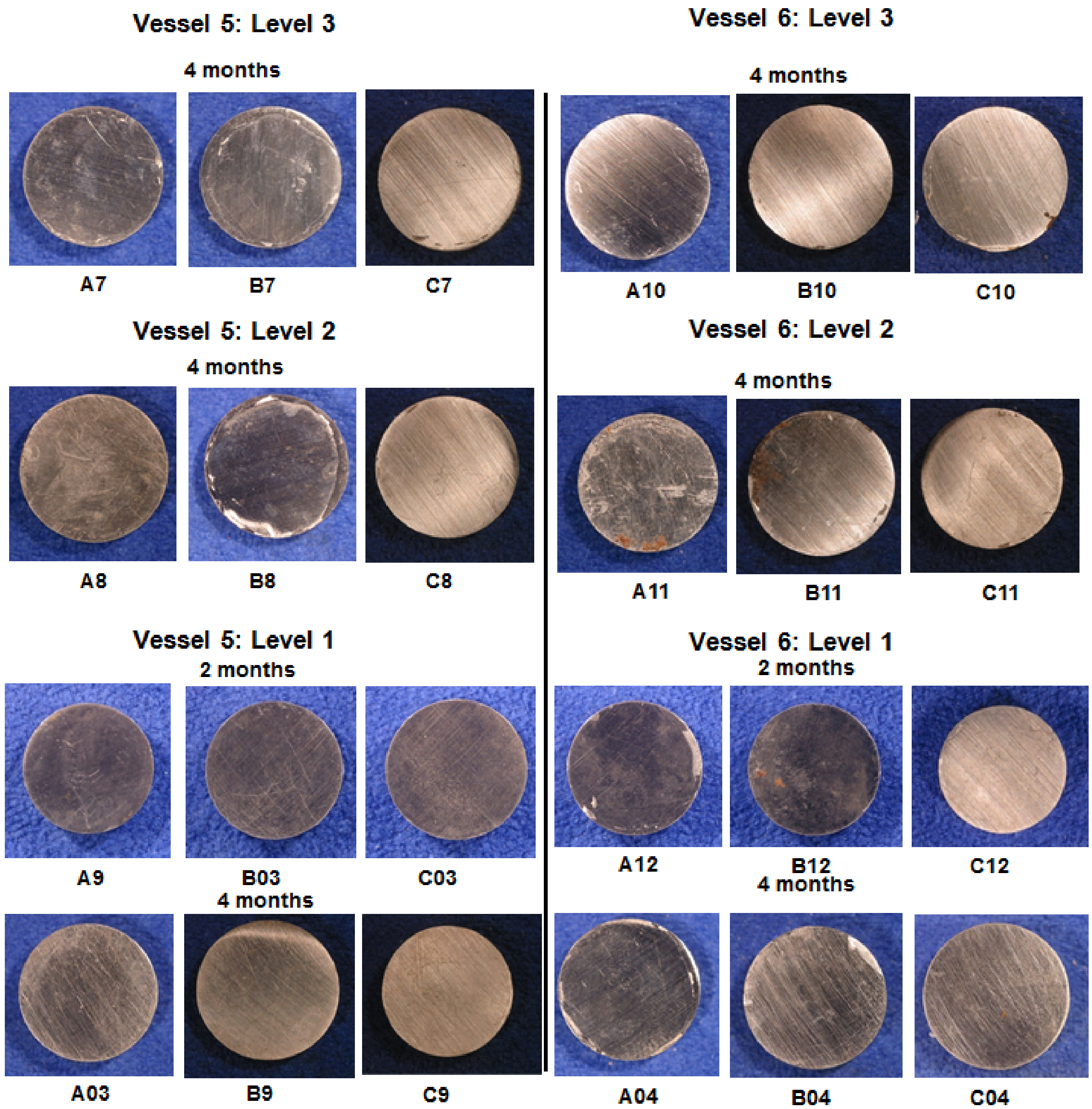


Figure 5-7 Pictures after VS exposure in simulant 5 and 6 at three different levels

Table 5-4 Weight losses and corrosion rates of coupons at different levels in Vessels 5 and 6

Vessel number	Coupon number	Level in vessel	Time exposure (month)	Weight loss (g)	Corrosion rate (mpy)
5	A7	High (Level3)	4 months	0.0003	0.02
	B7	High (Level3)	4 months	0.0000	0.00
	C7	High (Level3)	4 months	0.0001	0.01
	A8	Middle (Level 2)	4 months	0.0000	0.00
	B8	Middle (Level 2)	4 months	0.0000	0.00
	C8	Middle (Level 2)	4 months	0.0000	0.00
	A9	Low (Level 1)	2 months	0.0000	0.00
	A03	Low (Level 1)	4 months	0.0001	0.01
	B03	Low (Level 1)	2 months	0.0000	0.00
	B9	Low (Level 1)	4 months	0.0000	0.00
	C03	Low (Level 1)	2 months	0.0000	0.00
	C9	Low (Level 1)	4 months	0.0003	0.02
6	A10	High (Level3)	4 months	0.0000	0.00
	B10	High (Level3)	4 months	0.0000	0.00
	C10	High (Level3)	4 months	0.0000	0.00
	A11	Middle (Level 2)	4 months	0.0000	0.00
	B11	Middle (Level 2)	4 months	0.0000	0.00
	C11	Middle (Level 2)	4 months	0.0000	0.00
	A04	Low (Level 1)	2 months	0.0000	0.00
	A12	Low (Level 1)	4 months	0.0000	0.00
	B12	Low (Level 1)	2 months	0.0001	0.02
	B04	Low (Level 1)	4 months	0.0002	0.02
	C12	Low (Level 1)	2 months	0.0000	0.00
	C04	Low (Level 1)	4 months	0.0000	0.00

5.2 Vapor Space Corrosion tests at new SCC limits at different ammonia concentrations

A simulant consisting of 0.4 M nitrate was utilized for VSC tests at two concentrations of ammonia gas: 50 and 550 ppm. The simulant is at the borderline of the new proposed SCC limits with a nitrite/nitrate ratio of 0.15. Results from FY14 showed that there was no appreciable vapor space corrosion at the surface even at 50 ppm of ammonia. However by using acrylic and clear nail polish to mount the coupons, appreciable crevice corrosion was observed [8].

For this test, coupons were mounted in epoxy and tests were run for four months at three different levels. Coupons were also removed at two months intervals for the lowest level (Level 1). Pictures of coupons after test during these intervals are shown in Figure 5-8. Vessel 1 and Vessel 3 corresponds to the coupons exposed in humidified 50 ppm and 550 ppm ammonia gas, respectively. When the coupons were removed, there was no indication of crevice corrosion around the sides and back of the coupons. Since crevice corrosion was successfully prevented by the epoxy mount and epoxy coat at the edges, corrosion at the vapor space was able to be identified and quantified with corrosion rates determined by weight loss. However, it is important to state that by adding the epoxy coat around the edges, some condensation of the vapor may collect near the edges of the coating and carbon steel, helping to further corrosion by providing an electrolyte. As observed in the pictures, most of the corrosion is connected to the edges of the coupon so it may have started because of the condensation, although it is unclear. Comparing the levels, it is clear that corrosion was more severe at Level 1 than the other levels as it was observed during FY14 and at Level 1 corrosion did not progress with time. It does not appear to be a distinction of pre-treatment and level of corrosion for the two vessels.

Table 5-5 presents the weight loss and corrosion rates for these coupons. Corrosion rates for coupons at Levels 2 and 3 are almost negligible so in general, the corrosion attack is superficial and does not progress into the alloy. On the other hand, for coupons close to the simulant level and periodically wetted, corrosion rates were more severe in some cases and negligible in others. For example, A01 had the highest corrosion rate with a value of 0.66 mpy, but for the same condition with 550 ppm of ammonia, the corrosion rate was 0.12 mpy (A6). This is clearly an indication of other parameters affecting corrosion of the coupons rather than pre-treatment (i.e., weld and heat treatment), amount of ammonia in the vapor space and time of exposure in the vessel. Generally, a pattern could not be identified and the main points that were observed were that coupons close to the liquid level and constantly being wetted have a predisposition to more corrosion attack than at levels 2 and 3, and the concentration of ammonia between 50 and 550 ppm does not show a different grade of attack.

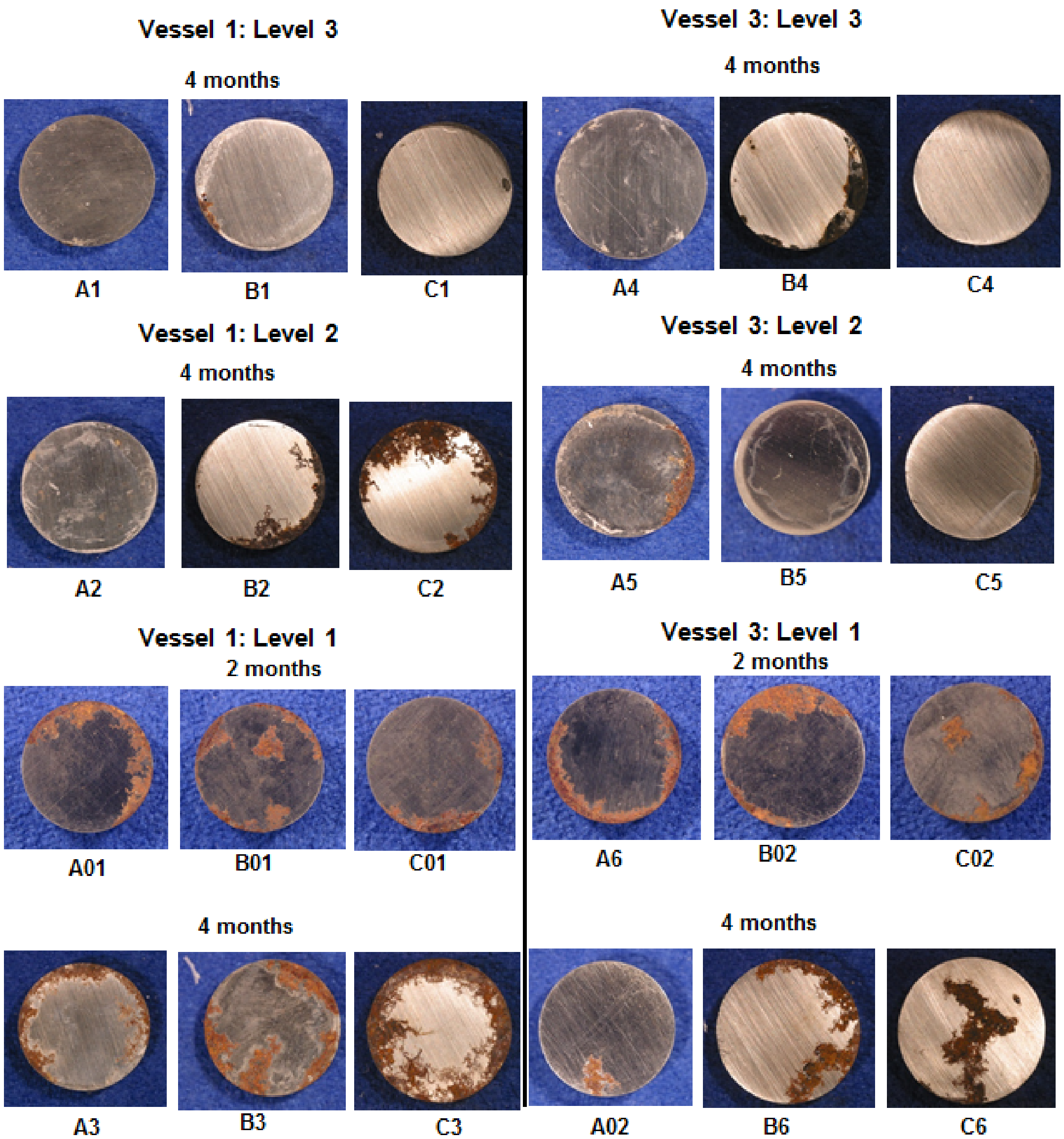


Figure 5-8 Fourth-month exposure at VS conditions of carbon steel in Vessels 1 and 3 at 50 ppm Ammonia and 550 ppm, respectively

Table 5-5 Weight losses and corrosion rates of coupons at different levels in Vessels 1 and 3

Vessel number	Coupon number	Level in vessel	Time exposure (month)	mass loss (g)	Corrosion rate (mpy)
1 (50 ppm), 40°C	A1	High (Level3)	4 months	0.0000	0.00
	B1	High (Level3)	4 months	0.0000	0.00
	C1	High (Level3)	4 months	0.0003	0.02
	A2	Middle (Level 2)	4 months	0.0000	0.00
	B2	Middle (Level 2)	4 months	0.0004	0.03
	C2	Middle (Level 2)	4 months	0.0003	0.02
	A01	Low (Level 1)	2 months	0.0040	0.66
	A3	Low (Level 1)	4 months	0.0009	0.07
	B01	Low (Level 1)	2 months	0.0031	0.51
	B3	Low (Level 1)	4 months	0.0005	0.04
	C01	Low (Level 1)	2 months	0.0019	0.31
	C3	Low (Level 1)	4 months	0.0004	0.03
3 (550 ppm), 40°C	A4	High (Level3)	4 months	0.0002	0.02
	B4	High (Level3)	4 months	0.0005	0.04
	C4	High (Level3)	4 months	0.0000	0.00
	A5	Middle (Level 2)	4 months	0.0002	0.02
	B5	Middle (Level 2)	4 months	0.0000	0.00
	C5	Middle (Level 2)	4 months	0.0003	0.02
	A6	Low (Level 1)	2 months	0.0007	0.12
	A02	Low (Level 1)	4 months	0.0039	0.32
	B02	Low (Level 1)	2 months	0.0031	0.51
	B6	Low (Level 1)	4 months	0.0003	0.02
	C02	Low (Level 1)	2 months	0.0038	0.63
	C6	Low (Level 1)	4 months	0.0004	0.03

5.3 Liquid Air Interface tests at new SCC limits

Liquid Air Interface tests were performed with different ratios of nitrite and nitrate. Welded coupons with no and different heat pre-treatments were exposed for four months in four different simulants. Figure 5-9 shows pictures after tests of the carbon steel coupons. As observed in the pictures, none of the coupons exhibited corrosion attack below the LAI and confirms previous findings in FY14 report [8]. Also coupons exposed in solution 3 showed no corrosion and coupons in solution 4 showed minimal corrosion, similar to what is was observed in FY14. This can be expected since it provided a large ratio of nitrite to nitrate (1.66) for any type of corrosion attack as required by the SRS inhibitor requirements for pitting control [21]. The only coupon that appears to have any sign of LAI corrosion is C2 in solution 2.

Comparing these pictures to weight losses and corrosion rates displayed in Table 5-6, they correlate well to what it was observed in the pictures. There were no or negligible weight losses for coupons exposed in solutions 3 and 4. Also, there were corrosion rates of less than 0.22 in all the other samples, except for C2 which it had a corrosion rate of 4.75 mpy. This corrosion rate is about 182% different from the highest corrosion rate obtained from the treated coupons studied and about 5 times higher than what is what observed for the base metal in the same simulant (0.79 mpy) [8].

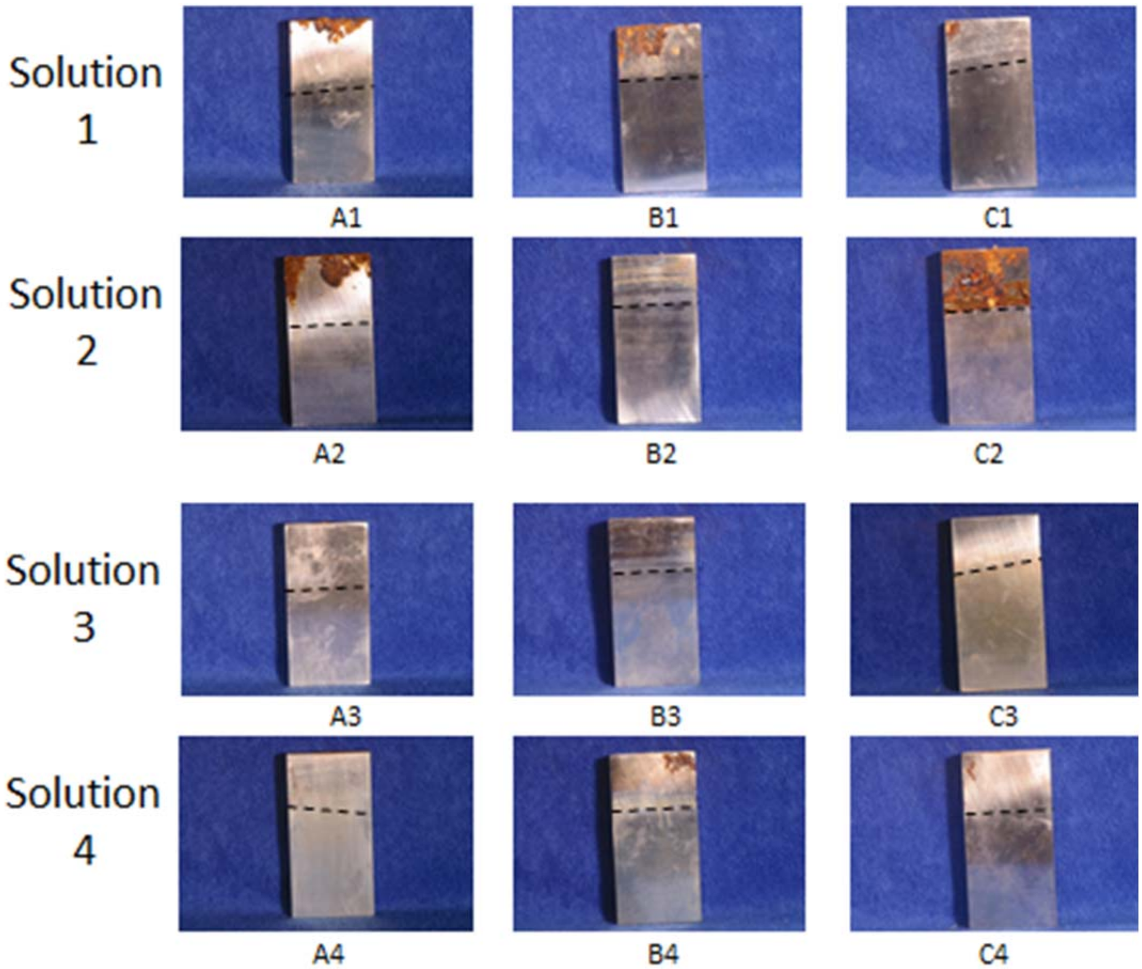


Figure 5-9 Pictures of coupons after two months and four months exposure during LAI testing for solutions 1, 2, 3 and 4. The dash line represents the interface.

Table 5-6 Weight losses and corrosion rates for carbon steel coupons exposed to Solutions 1 to 4 for 4 months

Solutions	Four month exposure - Liquid-Air Interface Immersion		
	Coupon name	weight loss (g)	Corrosion rate (mpy)
1	A1	0.0139	0.06
1	B1	0.0295	0.14
1	C1	0.0046	0.02
2	A2	0.0487	0.22
2	B2	0.0000	0.00
2	C2	1.0323	4.75
3	A3	0.0001	0.00
3	B3	0.0000	0.00
3	C3	0.0000	0.00
4	A4	0.0000	0.00
4	B4	0.0013	0.01
4	C4	0.0000	0.00

OCP transients for solutions 1 to 4 are shown in Figure 5-10 to Figure 5-12 for conditions A, B and C. The OCP values started at more than -200 mV and during the first several days increased to more noble potentials. For solutions 3 and 4 that had negligible or no corrosion, the OCP increased moderately and stabilized at more noble values independent of any pre-treatment of the carbon steel, similar to OCPs for the base metal in these solutions [8]. However for solutions 1 and 2, the OCP had more noise and went to more active potentials during the course of the test. In some cases, it went down close -400 mV indicating high corrosion activity. This also indicated a poor development of a protecting oxide film to help in corrosion inhibition. For C2, which had the highest corrosion rate, the OCP transient showed a very active region during the four month period which contributed to the highest weight loss seen. In comparison with the base metal immersed in solutions 1 and 2, OCPs from solution 1 went to more active potentials than in solution 2.

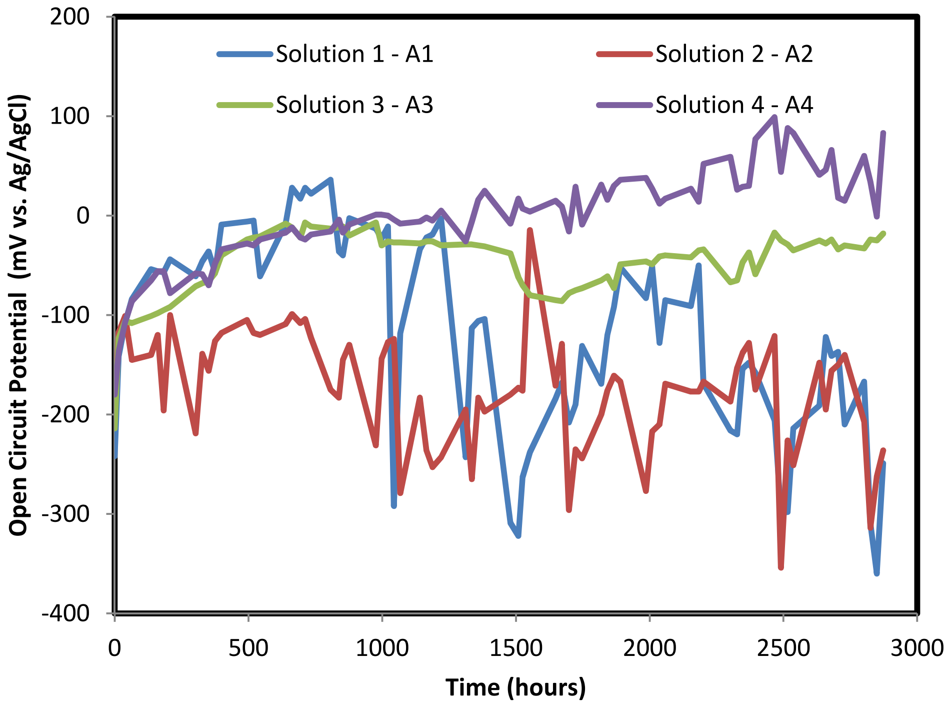


Figure 5-10 OCP measurements at different periods during four month testing of LAI for Solutions 1 to 4 for condition B.

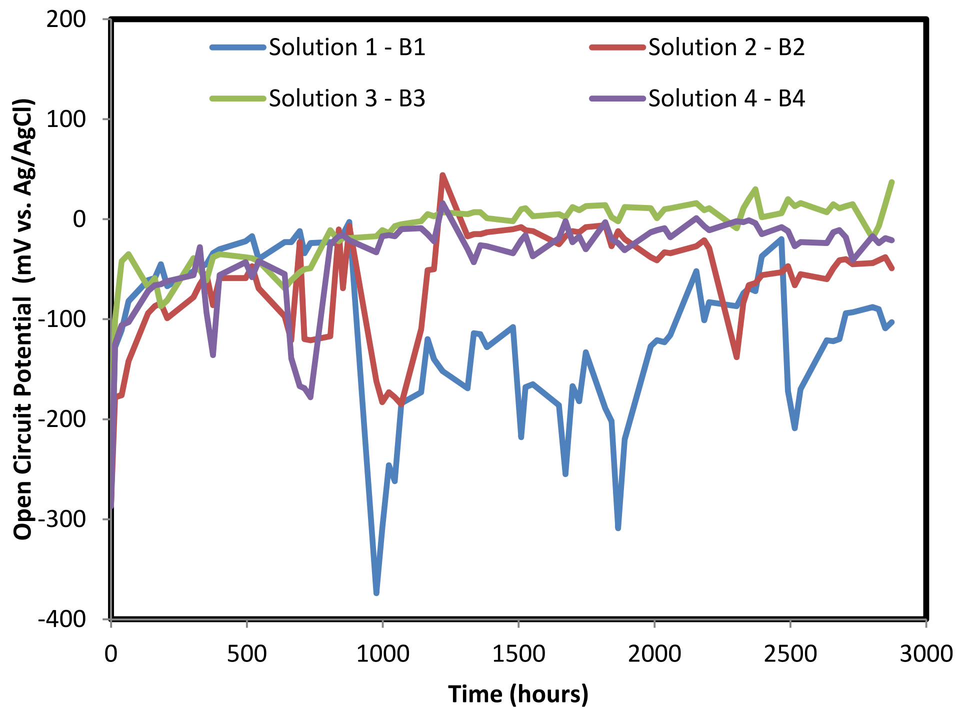


Figure 5-11 OCP measurements at different periods during four month testing of LAI for Solutions 1 to 4 for condition B.

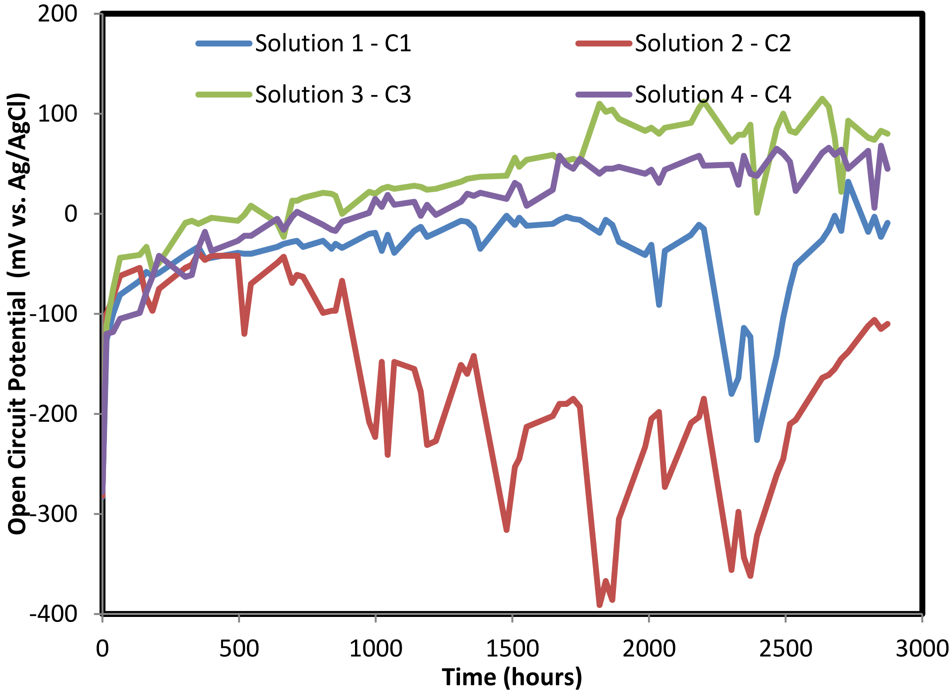


Figure 5-12 OCP measurements at different periods during four month testing of LAI for Solutions 1 to 4 for condition C.

Measurement of pit diameter and depth was obtained for the carbon steel coupons and the results are summarized in Table 5-7. Very small areas of general corrosion were seen with less than 30% corrosion areas in the most corroded samples. For solutions 3 and 4, there was no pitting observed except for B3 which has very small pits with a maximum depth of 0.6 mils. For C2, which had the highest corrosion rate, there were more areas of general corrosion seen but the pits were not larger and deeper than other cases. No pits were observed in the weld area of the coupons.

Table 5-7 Pitting diameter and depth range of solutions using the new SCC limits. Percentages were obtained by a qualitative assessment.

Solution	Coupon name	Time exposed (months)	diameter range (mils)	depth range (mils)	Remarks
1	A1	4	1.5-15.6	0.5-2.1	GA observed in less than 10% of coupon in the top area. No pits observed in the rest of the coupon and the weld area. No LAI corrosion observed.
2	A2	4	1.4-12.2	0.2-7.1	GA observed in the top area of the coupon with less than 20%. No pits observed in the rest of the coupon and the weld area. No LAI corrosion observed.
3	A3	4	N/A	N/A	No GA and/or pitting observed in the coupon.
4	A4	4	N/A	N/A	No GA and/or pitting observed in the coupon.
5	B1	4	0.9-7.1	0.6-2.2	GA observed in less than 20% of coupon in the top area. No pits observed in the rest of the coupon and the weld area. No LAI corrosion observed.
6	B2	4	0.2-0.3	0.1-0.4	GA observed in less than 5% of coupon in the top area. No pits observed in the rest of the coupon and the weld area. No LAI corrosion observed.
7	B3	4	0.6-0.9	0.2-0.6	Very small pits were observed above LAI. Corrosion of the weld was not observed. No LAI corrosion observed.
8	B4	4	N/A	N/A	No GA and/or pitting observed in the coupon.
9	C1	4	1.6-6.8	0.4-1.6	Very small pits were observed above LAI. Corrosion of the weld was not observed. No LAI corrosion observed.
10	C2	4	1.2-15.3	0.6-4.2	GA observed in less than 30% of coupon in the top area. No pits observed in the rest of the coupon and the weld area. No LAI corrosion observed.
11	C3	4	N/A	N/A	No GA and/or pitting observed in the coupon.
12	C4	4	N/A	N/A	No GA and/or pitting observed in the coupon.

GA – General Attack

5.4 Pitting Corrosion studies using the standardized CPP protocol for Argentinian work

Electrochemical tests were carried out in duplicate on 30 simulated tank solution formulas presented in Table 4.9. This work was completed in FY16 and the electrochemical results are presented in Appendix F.

Table 5-8 summarizes the results of the CPP curves measured for the solution chemistries given for each test. The CPP curves are ranked by categories 1 thru 5. These categories were defined in the FY14 report [8] and in RPP-ASMT-59979 [24]. Twenty-four of the 30 tests resulted in pitting corrosion with a majority of those showing pitting corrosion exhibiting a category 4 behavior. There were 6 cases of category 1 behavior, which indicated no pitting susceptibility.

The results of the repeated Argentina tests compared relatively well to original CPP test results. From the 18 tests, 14 tests produced the same observation (3 no pitting cases and 11 pitting cases). Two cases (Tests 6 and 17) that predicted no pitting, exhibited pitting during the Argentina studies. Based on similar test conditions with higher nitrite concentrations (e.g., Test 5 vs. Test 6), the results in this study were unexpected and thus these tests should be repeated before they are added to a database of pitting results. Two cases (Tests 7 and 13) that predicted pitting did not exhibit pitting during the Argentina studies. Due to the higher pH of these solutions, pitting may be unexpected in these cases. These tests should also be repeated before they are added to a database of pitting results.

The results of the final 12 tests in solutions with nitrate concentrations ranging between 0.5 – 2 M resulted in 11 of the 12 cases indicating pitting. The tests indicate that a pH of 12 is not always sufficient to prevent pitting initiation. Low nitrite concentrations or high concentrations of nitrate, chlorides and sulfate relative to nitrite may initiate pitting. New chemistry limits cannot rely on a pH limit of 12 if the concentration ranges of these aggressive species are within this tested range.

The results from these tests, along with other previous testing, will be utilized during FY16 for the development of new corrosion chemistry limits for the prevention of pitting.

Table 5-8 A summary of the pitting corrosion studies using the standard CPP protocol for test with the composition in moles per liter and the CPP result defined by category

Pitting Corrosion Test Results

Test	NaOH	$NaNO_2$	$NaNO_3$	NaCl	NaF	Na_2SO_4	pH	Run 1	Run 2	Ref. 2[a]
1	0	0.5	0.1	0.01	0.003	0.1	11.57	1	1	1
2	0	0.5	0.1	0.01	0.02	0.005	11.45	1	1	1
3	0	0.02	0.1	0.06	0.02	0.1	11.08	4	4	4
4	0	0.02	0.1	0.4	0.003	0.005	10.84	4	4	4
5	0	0.5	0.1	0.4	0.003	0.1	11.3	4	4	4
6	0	0.1	0.1	0.4	0.05	0.1	10.77	1	1	4
7	0.01	0.1	0.1	0.06	0.003	0.1	11.87	4	4	1
8	0.01	0.1	0.7	0.06	0.05	0.005	11.88	4	4	4
9	0.01	0.02	0.7	0.06	0.05	0.1	11.7	4	4	4
10	0.01	0.5	0.1	0.4	0.02	0.005	12.12	4	4	4
11	0.01	0.1	0.7	0.01	0.003	0.005	13.15	1	4	1
12	0.1	0.02	0.1	0.01	0.05	0.005	13.06	4	4	1,WA[b]
13	0.1	0.5	0.1	0.01	0.02	0.1	13.03	1	1	1
14	0.1	0.1	0.1	0.06	0.05	0.005	13.15	4	4	1
15	0.1	0.02	0.1	0.4	0.003	0.1	13.166	4	4	4
16	0.1	0.5	0.1	0.4	0.003	0.005	12.98	4	4	4
17	0.1	0.02	0.1	0.4	0.02	0.1	12.92	1	1	4
18	0.1	0.5	0.7	0.4	0.02	0.1	13.03	4	4	4
19	0.01	0.1	0.5	0.06	0.003	0.005	12	4	4	
20	0.01	0.5	0.5	0.06	0.01	0.1	12	4	2	
21	0.01	1	0.5	0.4	0.003	0.005	12	4	4	
22	0.01	0.5	1	0.06	0.01	0.005	12	2	2	
23	0.01	1	1	0.06	0.003	0.1	12	2	2	
24	0.01	1.5	1	0.4	0.01	0.1	12	3	4	
25	0.01	1	1.5	0.06	0.003	0.1	12	1	1	
26	0.01	1.5	1.5	0.4	0.003	0.005	12	3	4	
27	0.01	2	1.5	0.4	0.01	0.005	12	4	4	
28	0.01	1	2	0.06	0.01	0.1	12	4	4	
29	0.01	1.5	2	0.4	0.01	0.005	12	4	4	
30	0.01	2	2	0.06	0.003	0.1	12	2	2	

[a.] Test solutions 1 thru 18 were previously reported in reference 2.

[b.] The previous report referred to the corrosion attack as "water line attack" which insinuates a liquid-air-interface and the attack was at that interface.

5.5 Waste Buffering of simulant from DST AN-102

Electrochemical testing was performed with AN-102 simulants with different concentrations of nitrate, nitrite and hydroxide. During FY14, the testing focused on concentrations of nitrate from 2.90 to 3.77 M, nitrite from 1.00 to 2.24 M and low ranges of hydroxide from 0.032 to 0.262 M. Also temperatures were varied from 30 to 50 °C. The results indicated no pitting with all curves showing negative hysteresis [8]. For FY15, there were 18 tests selected for waste buffering testing with a large concentration variance of nitrate (i.e., 1.1 to 5.5 M), small range and low concentrations for nitrite (i.e., 0.5 to 1.5 M) and very low concentrations of hydroxide (i.e., 0.01 and 0.05 M) at 40 °C.

Initially, simulants were prepared for tests 7 to 12 that contained the same amount of nitrate and test 13 which contained the largest concentration of nitrate. Table 5-9 shows the conditions and a summary of the electrochemical testing using the original simulant for these tests. In summary, negative hysteresis and no pitting was found when the concentration of nitrite was increased to 1.5 M at 0.01 M hydroxide and increased to 1.0 M at 0.05 M hydroxide.

Table 5-9 Concentration and summary of results using original waste buffering simulant for electrochemical testing

Test	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	Hysteresis	Pitting on Sample?
7	3	0.5	0.01	12.12	Pos/Mixed	Major
8	3	1	0.01	11.54	Negative	Minor
9	3	1.5	0.01	12.4	Negative	None
10	3	0.5	0.05	12.57	Mixed	Minor
11	3	1	0.05	12.3	Negative	None
12	3	1.5	0.05	12.13	Negative	None
13	5.5	0.5	0.01	12.41	Mixed	Major

Figure 5-13 and Figure 5-14 show the CPP results and pictures of the coupon under the microscope of nose and shank after testing for tests 7 and 10. These two cases represent the same concentration of nitrate and nitrite with a small change in concentration of hydroxide. As seen in the CPP curves, the open circuit started close to -0.6 V vs. SCE then it goes into the passive regime and then to the transpassive region in the forward scan. This behavior was observed in all CPP curves for this task. The backward scan is mostly what changes. By the disruption of the oxide layer, the carbon steel can repassivate observed by a decreased in current density or corrode by the increase in current density. The former can be observed by the appearance of negative hysteresis while the latter is observed by positive hysteresis. Borderline cases are represented by mixed hysteresis and the appearance of this behavior gives inconclusive results. The two cases described in these figures show borderline cases with mixed hysteresis. As observed in the CPP curves by the increase in hydroxide concentration from 0.01 to 0.05 M, the hysteresis goes from being positive/mixed to mixed and the pitting from major became minor. This indicates that the addition in concentration of just 0.05 M hydroxide can help inhibit the carbon steel for localized corrosion, although not completely.

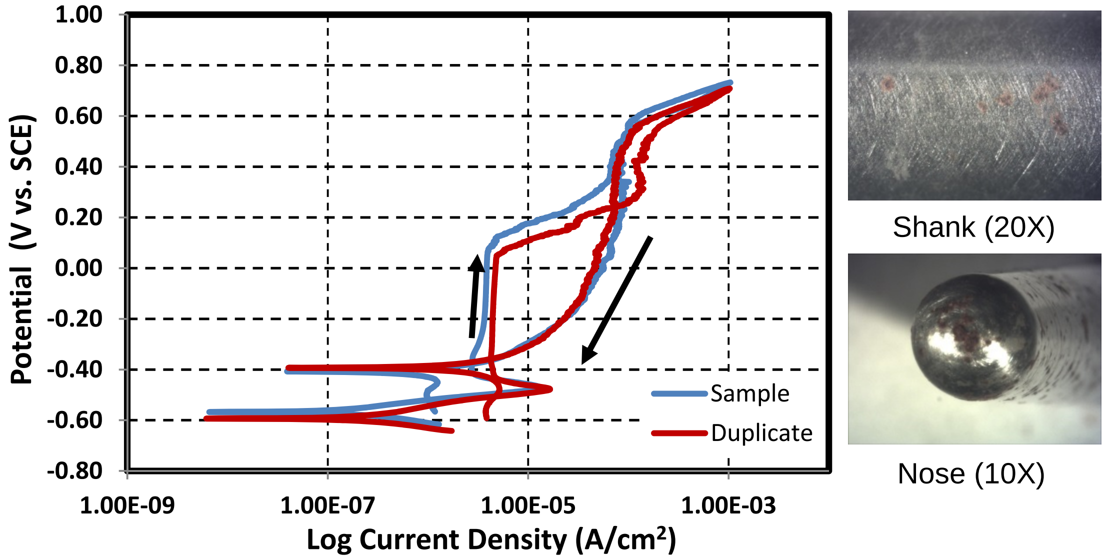


Figure 5-13 Cyclic potentiodynamic polarization scans for sample and duplicate using conditions described in Test 7 using original simulant

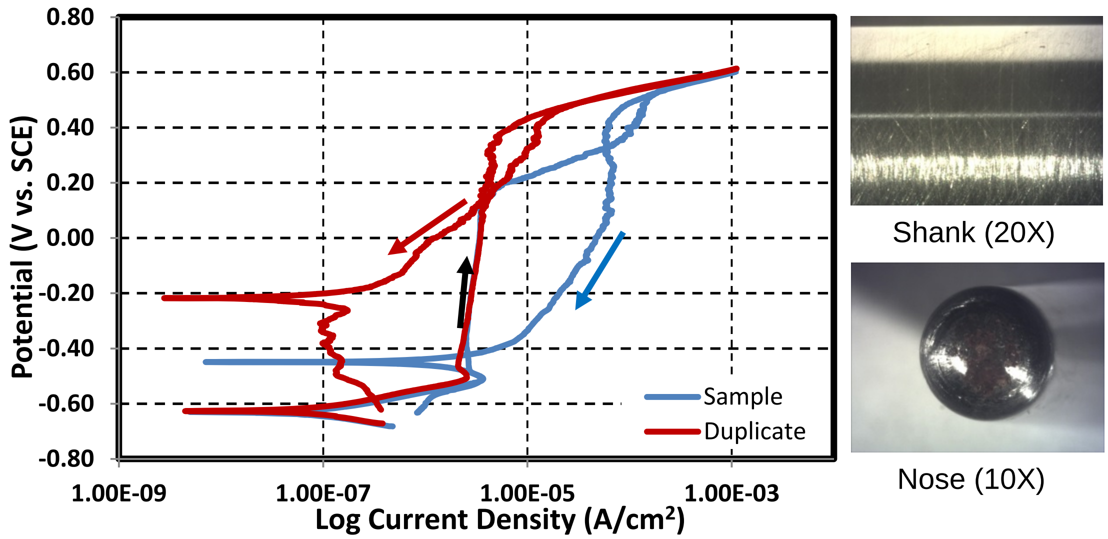


Figure 5-14 Cyclic potentiodynamic polarization scans for sample and duplicate using conditions described in Test 10 using original simulant

After performing experiments from solutions 7 to 12, we started to make the simulant for test 13. Since this simulant has a very high nitrate concentration (5.5 M), it did not dissolve completely into solution even with stirring and heating to 40 °C. However, CPP tests were performed. We also realized at this point that the original simulant had a minimum concentration of nitrate of 1.574 M which most of it comes from the high concentration of aluminum nitrate used (0.5 M). In conversations with the TIEP Corrosion subgroup, the simulant was modified to accommodate for less concentration of aluminum nitrate from 0.5 to 0.005 M which decreased the nitrite content to 1.1 M to accommodate for the testing at low nitrate concentration (Test 1 to 6). This, in turn, decreased the alkalinity of the solution. The decrease in pH was not foreseen, so some testing was performed at the low pH. Table 5-10 presents the results of the testing using this modified simulant. It was observed that pH values were less than 12. When the pH was adjusted to 12 for 0.01 M hydroxide and 12.7 for 0.05 M hydroxide using a solution of sodium hydroxide, testing was repeated and the results for these tests are shown in Table 5-11.

Table 5-10 Concentration and summary of results using modified waste buffering simulant for electrochemical testing

Test	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	Hysteresis	Pitting on Sample?
1	1.1	0.5	0.01	11.04	Neg/Pos	Minor/Major
2	1.1	1	0.01	11.13	Negative	None
3	1.1	1.5	0.01	11.05	Negative	None
4	1.1	0.5	0.05	11.35	Negative	Minor
5	1.1	1	0.05	11.44	Negative	None
6	1.1	1.5	0.05	11.39	Negative	None
7	5.5	0.5	0.01	11.34	Mixed	Major

Table 5-11 Concentration and summary of results using modified waste buffering simulant for electrochemical testing with pH adjustment

Test	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	pH after adjusting at 40°C	Hysteresis	Pitting on Sample?
1	1.1	0.5	0.01	11.02	12.04	Negative	Minor
2	1.1	1	0.01	11.41	12.07	Negative	None
3	1.1	1.5	0.01	11.02	12.01	Negative	None
4	1.1	0.5	0.05	11.91	12.74	Negative	Minor
5	1.1	1	0.05	12.09	12.76	Negative	None
6	1.1	1.5	0.05	12.06	12.74	Negative	None
7	3	0.5	0.01	11.34	12.01	Mixed	Major

As shown in the tables above, the outcome of the CPP and pitting was very similar for all testing except for Test 1 in which the duplicate had positive hysteresis and major pitting. Still, the change in pH did not contribute to exacerbate the corrosion of the carbon steel with the same concentrations of nitrate, nitrite and hydroxide.

To demonstrate that same results can be obtained with the original and modified simulant and to validate the modified simulant to run all the other tests, Test 7 was run with the modified simulant and with the adjusted pH. Test 7 was selected because it represents a borderline condition for localized pitting and similar results will indicate validation of the simulant. CPP results as well as the pictures under the microscope for the shank and nose for the modified simulant with pH adjustment are observed in Figure 5-15. The CPP curve demonstrated mixed hysteresis with major pitting and the results are very similar to the CPP curve using the original formulation shown in Figure 5-13. These results validated the modified simulant to use in other tests.

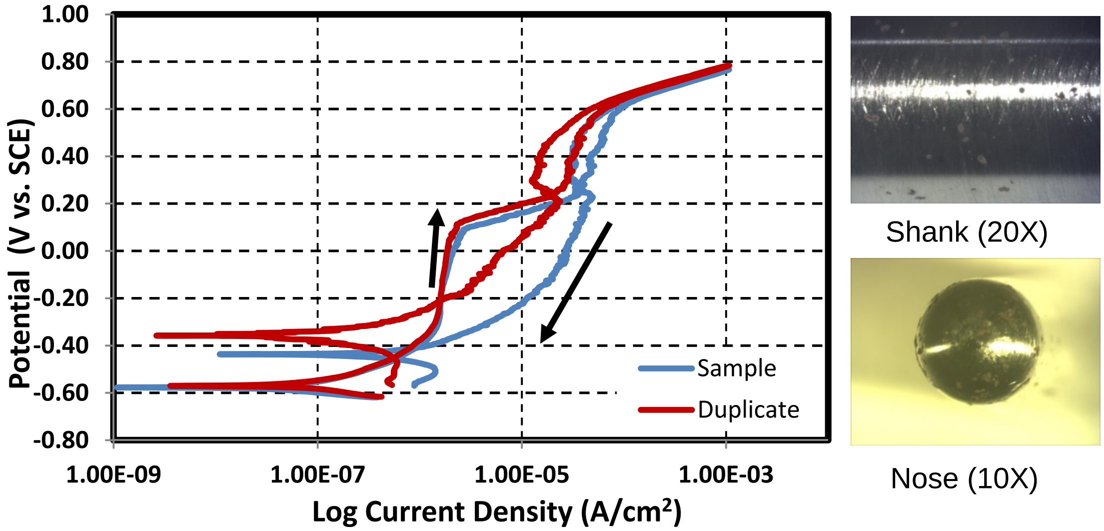


Figure 5-15 Cyclic potentiodynamic polarization scans for sample and duplicate using conditions described in Test 7 using modified simulant with pH adjustment

Ongoing with Test 13, it was found that the 5.5 M nitrate was too high for complete dissolution in water, nevertheless the electrochemical experiment ran with these conditions. Figure 5-16 (a) shows the CPP curve using the original simulant with incomplete dissolution. It can be noticed that mixed hysteresis was obtained with sample and duplicate. Test 13 was also run with the modified simulant with no pH adjustment and the results are displayed in Figure 5-16 (b). However there was also incomplete dissolution of the nitrate salts in the water.

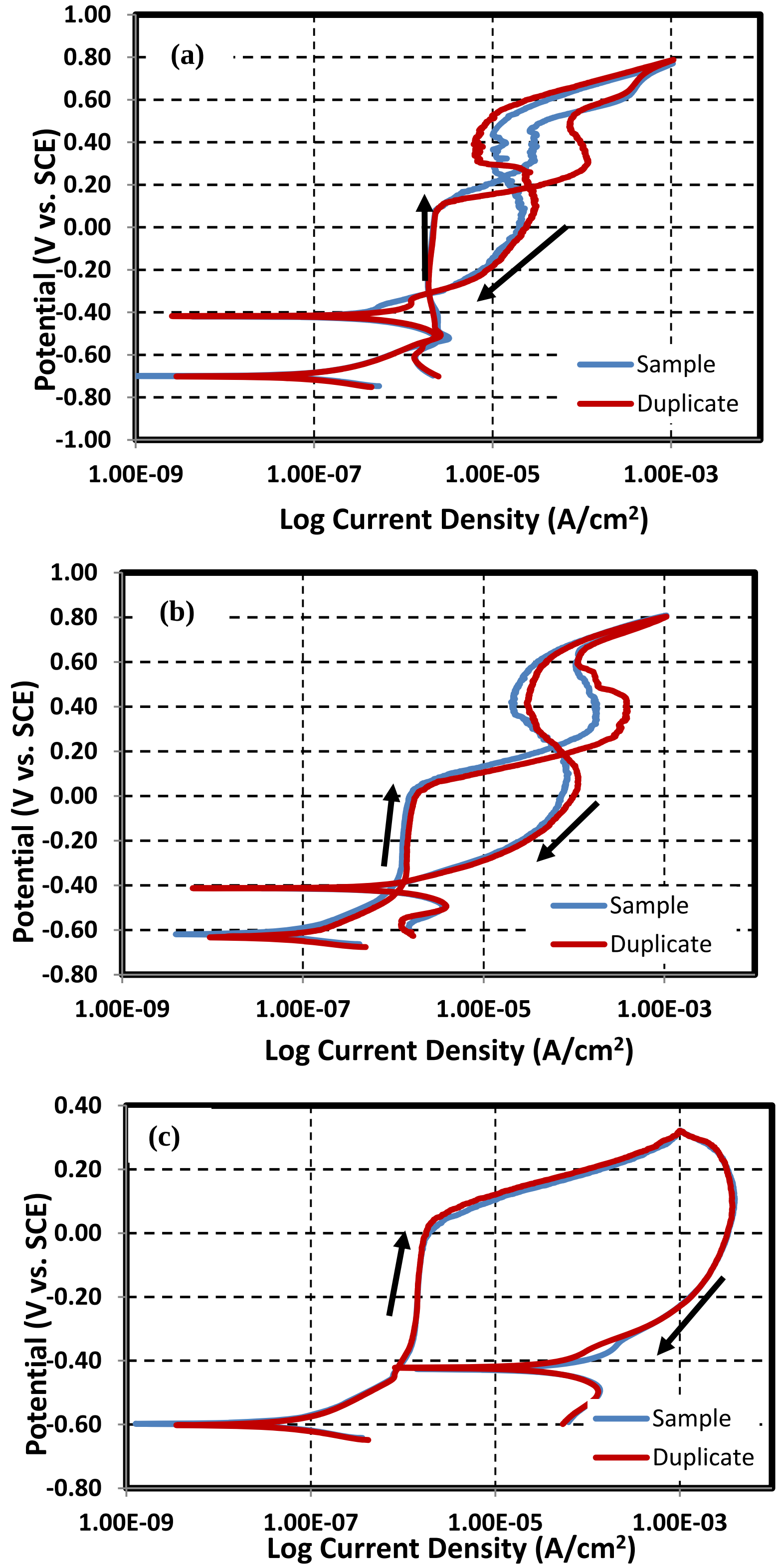


Figure 5-16 Cyclic potentiodynamic polarization scans for sample and duplicate using conditions described in Test 13 using (a) original simulant, (b) modified simulant with no pH adjustment and (c) modified simulant with concentration and pH adjustment

It was decided that for the next experiments at high nitrate concentrations, the quantities of nitrate added will be monitored and adjusted depending on the solubility. Small quantities of sodium nitrate were added at the end in 10 grams increments with agitation and at the test temperature (40 °C). By adding small quantities the final concentration of nitrate that was able to dissolve in solution was determined and for Test 13 this final concentration was about 5 M nitrate. The CPP results for this test are presented in Figure 5-16 (c). CPP curves for (a) and (b) looked very similar. Both had a mixed hysteresis profile with a transpassive behavior that started around 0.2 V vs. SCE. In contrast, Figure 5-16 (c) showed a positive hysteresis and equal trend for sample and duplicate. However, all three cases showed major pitting. These results showed that the carbon steel at those conditions independently of the adjustment of pH and concentration is more propense to localized corrosion. It was decided to continue to do the testing adjusting the concentration and pH for the high concentration of nitrate tests, since at least by having complete dissolution of the salt is indicative of a uniform concentration in the solution. Therefore, by complete dissolution it can be established the real concentration of nitrate in equilibrium. Table 5-12 presents the adjusted concentrations of the high nitrate testing. It can be noticed that a similar concentration was obtained depending on the nitrite concentration and independent with hydroxide concentration.

Table 5-12 Concentration and summary of results using modified waste buffering simulant for electrochemical testing with pH and concentration adjustment

Test	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	pH after adjusting at 40°C	Hysteresis	Pitting on Sample?
13	5.004	0.5	0.01	11.69	12.01	Positive	Major
14	4.252	1	0.01	11.33	12.08	Negative	Minor
15	4.089	1.5	0.01	11.25	12.05	Negative	None
16	5.004	0.5	0.05	11.57	12.71	Mixed	Minor
17	4.252	1	0.05	11.32	12.72	Negative	None
18	4.089	1.5	0.05	11.46	12.71	Negative	None

- Red cells indicate modified concentration used to make sure the salts were completely dissolved in solution.

Similar trending of the results was obtained as tests 1 to 6 and 7 to 12. At a concentration of nitrite of 0.5 M and hydroxide of 0.01 M, CPP results obtained with positive and mixed hysteresis and with localized corrosion. Increasing the concentration of nitrite to 1.0 M while maintaining the hydroxide at 0.01 M, is a borderline condition. For a nitrate concentration of 1.1 M, independently of pH, there was negative hysteresis and no localized corrosion. When the concentration of nitrate was increased to 3 M and up, there was negative hysteresis with minor pitting observed. However, by only increasing the hydroxide from 0.01 M to 0.05 M, no pitting was observed. In solutions with a nitrite concentration of 1.5 M, there was negative hysteresis and no localized corrosion, independently of the concentration of nitrate and even with a concentration of hydroxide as low as 0.01 M.

5.6 Material Selection

The electrochemical corrosion tests, performed with 5 different A537 steels in two dilute waste solutions (see Table 4-12), were found to be susceptible to aggressive pitting corrosion at 25 °C. The plot in Figure 5-17 represents the results from A537 steel DNV-GL ID# 2311 (Dillinger). The reverse scan of the curve (red) is at a higher current than the forward scan (black) which indicated the sample has undergone pitting corrosion. For comparison, Figure 5-18 presents the results of the legacy A537 (DNV-GL ID# 1081), which likewise displays a positive hysteresis that indicates pitting corrosion. These two tests showed pitting corrosion in the carbon steel. Positive hysteresis in the CPP and pitting corrosion in the samples was obtained for the other three materials studied.

Further testing was not performed on this task due to work stoppage during FY15. While these results may be added to the pitting database, a decision was made to focus primarily on the effects of the environment for the development of the new chemistry limits for pitting control.

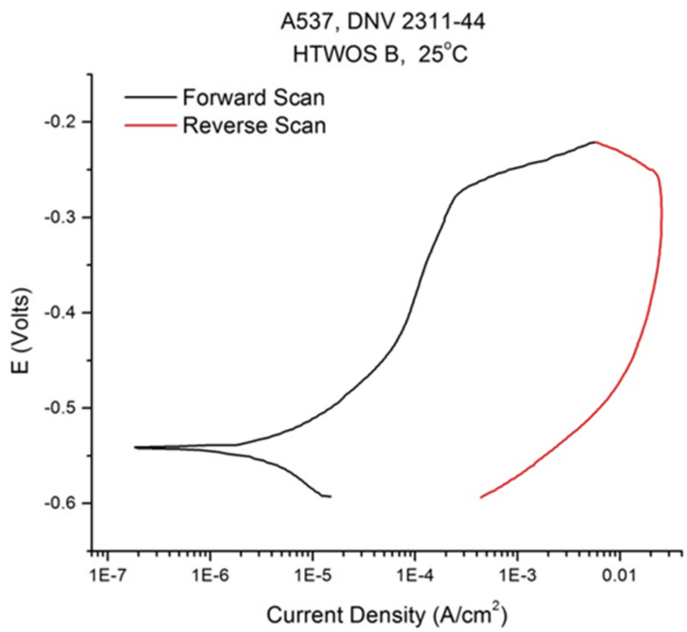


Figure 5-17 Cyclic potentiodynamic polarization curve for DNV-GL steel 2311-44 test.

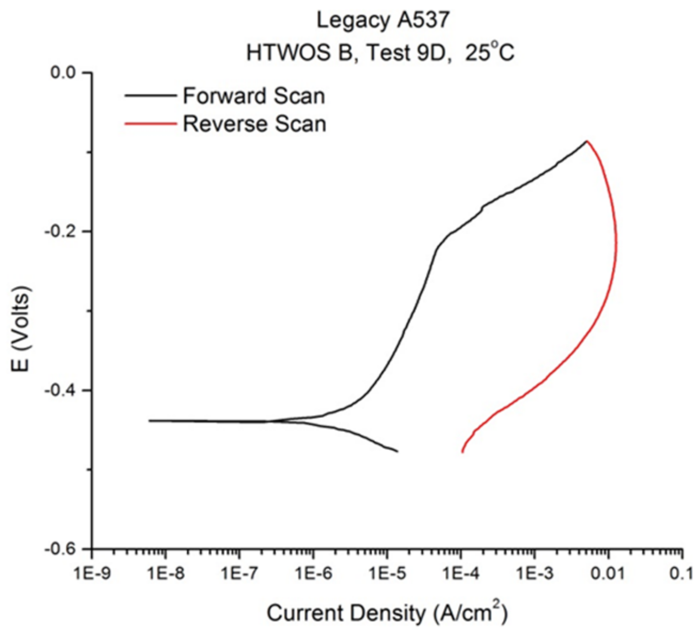


Figure 5-18 Cyclic potentiodynamic polarization curve for legacy A537 steel.

6.0 Conclusions

Five tasks were performed for FY15 to address six areas of concern for the DST waste chemistry control program. A brief summary and conclusions for the studies conducted is presented below.

6.1 Secondary Wall of AY-102 Tank Corrosion Studies

Total immersion (TI) and VSC studies were executed in simulated leak detection pit (LDP) and ground water (GW) simulants that are representative of the potential liquids present at the secondary wall of AY-102. Refractory waste simulants (i.e., AY-102 waste simulant that has contacted the refractory pad) were also studied, but only for VSC. During TI tests, general attack was observed on all samples exposed to the GW simulant. The rate was constant at approximately 10 mpy over the four month exposure period. In contrast, the corrosion rate for coupons exposed to the LDP simulant were higher for the initial two months and then decreased during the final two months of exposure to approximately half of the initial rate. Generally, the corrosion rate and the open circuit potential did not depend on the heat treatment and no distinctive corrosion patterns were observed in the weld region. For VSC testing, corrosion was more severe for coupons exposed above the GW simulant than the LDP simulant. In general, coupons close to the liquid level corroded significantly more than those located well above the liquid air interface. For the refractory simulants, a small degree of surface attack was observed, however, almost no weight loss was measured after four months of exposure. The high nitrite concentration at these conditions was a contributing factor for inhibiting corrosion.

6.2 Vapor Space Corrosion tests at new SCC limits with different concentrations of Ammonia gas in Air

A 0.4 M nitrate simulant, prepared according to the proposed new limits for stress corrosion cracking (SCC), was used to perform VSC test in atmospheres that contained between 50 and 550 ppm of ammonia. After four months of exposure, corrosion was more severe at the level next to the LAI than at the two higher levels. Coupons at the LAI had varied corrosion rates, whereas the coupons at the higher levels exhibited negligible corrosion. The corrosion rate did not depend on the heat treatment of the material or on the ammonia concentration present in the atmosphere.

6.3 Waste Buffering of simulant from DST AN-102

AN-102 simulant was utilized to investigate waste buffering at different concentrations of nitrate, nitrite and hydroxide. Eighteen tests were performed over a large range of nitrate (1.1 to 5.5 M), nitrite (0.5 to 1.5 M), and hydroxide (0.01 and 0.05 M) concentrations at 40 °C. No pitting susceptibility was observed when the concentration of nitrite was increased to 1.5 M at 0.01 M hydroxide or increased to 1.0 M at 0.05 M hydroxide independent of the nitrate concentration. Therefore, at low temperatures (i.e., less than 40°C) the amount of free hydroxide necessary to inhibit pitting was less than that required by the current waste chemistry control program provided there is sufficient nitrite present.

6.4 Liquid Air Interface tests at new SCC limits

LAI tests of carbon steel coupons exposed to simulants with different ratios of nitrite and nitrate were performed. Coupons exposed to simulants with a ratio of nitrite to nitrate of 1.66 showed negligible corrosion rates or pitting susceptibility. This can be expected since this inhibitor ratio meets the SRS requirement for pitting control. None of the coupons showed any signs of LAI. Minor areas of general surface attack were seen in the vapor space area. However, no pits or general corrosion areas were observed in the weld area of the coupons. There was also no correlation between heat treatment and the degree of corrosion observed.

6.5 Pitting Corrosion studies using the standardized CPP protocol for the Argentinian work and additional Dilute Tests Solutions

The results of the 18 repeated Argentina tests compared relatively well to original CPP test results. A second series of tests in simulants with nitrate concentrations ranging between 0.5 – 2 M resulted in 11 of the 12 cases indicating pitting. These results indicate that a pH of 12 is not always sufficient to prevent pitting initiation particularly if higher than normal quantities of chloride and sulfate are present. The results from these tests, along with other previous testing, will be utilized during FY16 for the development of new corrosion chemistry limits for pitting prevention.

6.6 Pitting corrosion studies using the standardized CPP protocol of new vs. legacy stock of A-537 steel for Vitrification Return Stream

All five heats of carbon steel underwent aggressive pitting corrosion in the two test simulants during the CPP test. To determine if there is an appreciable effect of the different heats of material, CPP testing in a simulant that is not aggressive and in one that produces mixed results may reveal differences.

7.0 Quality Assurance

Data for Tasks 1, 2 and 4 were recorded in the electronic laboratory notebook system, notebook number G8519-00126. Data for Task 3 and 5 were in the electronic laboratory notebook system, notebook number I7006-00164.

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

8.0 Acknowledgements

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10.0 Appendices

Appendix A
Chemical Composition of Simulants used in Vapor Space Corrosion Testing

Appendix B
Pictures of Vapor Space Corrosion Samples after Test

Appendix C
Chemical Composition of Simulants used in Liquid Air Interface and Total Immersion Corrosion Testing

Appendix D
Pictures of Liquid Air Interface and Total Immersion Corrosion Samples after Test

Appendix E
Open Circuit Potential, pH and Temperature vs. Time plots for LAI and TI Solutions

Appendix F
Chemical Composition of Simulants used in Pitting Corrosion (Task 3) with Electrochemical Results and Pictures after Test

Appendix G
Chemical Composition of Simulants used in Waste Buffering (Task 4) with Electrochemical Results and Pictures after Test

Appendix H
Electrochemical Results for Material Selection (Task 5)

Appendix A

Chemical Composition of Simulants used in Vapor Space Corrosion Testing

Composition of simulant for VS-Solution 1

Temperature	40	°C	Ammonia Gas	50 ppm
pH	12			
Volume	2	L		

Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Aluminum Nitrate	$Al(NO_3)_3.9H_2O$	375.1314	0.0002	0.1501
Sodium Chloride	NaCl	58.4400	0.01	1.1688
Sodium Fluoride	NaF	41.9882	0.003	0.2519
Sodium Sulfate	Na_2SO_4	142.0400	0.005	1.4204
Ammonium Nitrate	NH_4NO_3	80.0520	0.0012	0.1921
Sodium Hydroxide	NaOH	40.0000	0.01	0.8000
Sodium Phosphate	$Na_3PO_{4.}12H_2O$	380.1200	0.0005	0.3801
Sodium Carbonate	Na_2CO_3	105.9885	0.1	21.1977
Sodium Nitrate	$NaNO_3$	84.9947	0.400	67.9958
Sodium Nitrite	$NaNO_2$	68.9953	0.060	8.2794

Composition of simulant for VS-Solution 3

Temperature	40	°C	Ammonia Gas	550 ppm
pH	12			
Volume	2	L		

Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Aluminum Nitrate	$Al(NO_3)_3.9H_2O$	375.1314	0.0002	0.1501
Sodium Chloride	NaCl	58.4400	0.01	1.1688
Sodium Fluoride	NaF	41.9882	0.003	0.2519
Sodium Sulfate	Na_2SO_4	142.0400	0.005	1.4204
Ammonium Nitrate	NH_4NO_3	80.0520	0.0120	1.9212
Sodium Hydroxide	NaOH	40.0000	0.01	0.8000
Sodium Phosphate	$Na_3PO_{4.}12H_2O$	380.1200	0.0005	0.3801
Sodium Carbonate	Na_2CO_3	105.9885	0.1	21.1977
Sodium Nitrate	$NaNO_3$	84.9947	0.400	67.9958
Sodium Nitrite	$NaNO_2$	68.9953	0.060	8.2794

Composition of simulant for VS-Solution 5

Temperature	45	°C	Refractory	R-9
pH	9.92			
Volume	2	L		

Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Sodium Hydroxide	$NaOH$	40.0000	0.0006	0.045
Calcium Chloride	$CaCl_2$	110.9800	0.000023	0.005
Sodium Fluoride	NaF	41.9882	0.0653	5.484
Sodium metasilicate, 9-hydrate	$Na_2SiO_3.9H_2O$	284.20	0.0005	0.302
Sodium Oxalate	$Na_2C_2O_4$	134.00	0.00988	2.647
Sodium Chloride	$NaCl$	58.4400	0.06871	8.031
Sodium bicarbonate	$NaHCO_3$	84.0100	0.06993	11.749
Sodium Sulfate	Na_2SO_4	142.0400	0.28644	81.372
Sodium Carbonate	Na_2CO_3	105.9885	0.21	43.46
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.620	168.752
Sodium phosphate, 12-hydrate	$Na_3PO_{4.}12H_2O$	380.0000	0.000021	0.016
Disodium Phosphate, 7-hydrate	$Na_2HPO_4.7H_2O$	268.07	0.00009	0.049
Potassium Carbonate	K_2CO_3	138.205	0.12	34.551
Sodium Nitrite	$NaNO_2$	68.9953	3.0607	422.341
Sodium Nitrate	$NaNO_3$	84.9947	0.12	20.402

Composition of simulant for VS-Solution 6

Temperature	45	°C	Refractory	R-12
pH	9.85			
Volume	2	L		

Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Sodium Hydroxide	NaOH	40.0000	0.0001	0.004
Calcium Chloride	$CaCl_2$	110.9800	0.000383	0.085
Sodium Fluoride	NaF	41.9882	0.0035	0.297
Sodium Oxalate	$Na_2C_2O_4$	134.00	0.00246	0.659
Sodium Chloride	NaCl	58.4400	0.35006	40.915
Sodium bicarbonate	$NaHCO_3$	84.0100	0.08000	13.441
Sodium Sulfate	Na_2SO_4	142.0400	0.01010	2.87
Sodium Carbonate	Na_2CO_3	105.9885	0.05	10.6
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.540	146.977
Disodium Phosphate, 7-hydrate	$Na_2HPO_4.7H_2O$	268.07	0.00006	0.034
Potassium Nitrate	KNO_3	101.1	3.27000	661.194
Sodium Nitrite	$NaNO_2$	68.9953	5.6812	783.954
Sodium Nitrate	$NaNO_3$	84.9947	3.57	606.971

Composition of simulant for VS-Solution 7

Temperature	45	°C
pH	7.6	
Volume	2	L

Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Sodium bicarbonate	$NaHCO_3$	84.0100	1.120E-03	0.1882
Calcium hydroxide	$Ca(OH)_2$	74.0930	1.210E-04	0.0179
Potassium nitrate	KNO_3	101.1032	6.750E-05	0.0136
Magnesium Nitrate, 6-hydrate	$Mg(NO_3)_2.6H_2O$	256.4100	1.520E-05	0.0078
Strontium Nitrate	$Sr(NO_3)_2$	211.6300	4.040E-06	0.0017
Sodium sulfate	Na_2SO_4	142.0400	1.830E-06	0.0005
Sodium Metasilicate, 5-hydrate	$Na_2SiO_3.5H_2O$	212.1400	4.570E-05	0.0194
Ferric chloride	$FeCl_3$	162.2000	2.670E-06	0.0009
Manganese Nitrate	$Mn(NO_3)_2$	178.9500	3.430E-07	0.0001
Acetic Acid	$C_2H_4O_2$	60.0500	3.000E-04	0.0360

Composition of simulant for VS-Solution 8

Temperature	45	°C
pH	7.6	
Volume	2	L

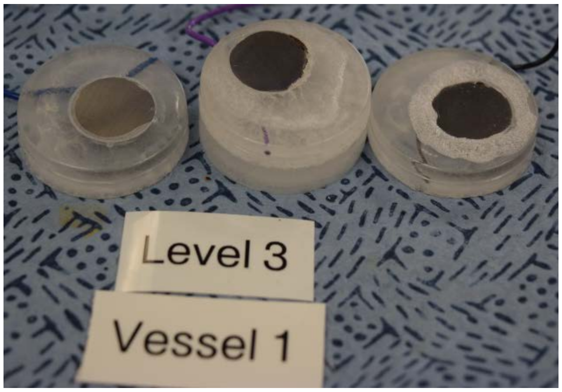
Simulant Source	Formula	Molecular weight (g/mol)	Concentration (M)	Weight required (g)
Sodium bicarbonate	$NaHCO_3$	84.0100	1.750E-03	0.2940
Calcium hydroxide	$Ca(OH)_2$	74.0930	1.500E-03	0.2223
Potassium nitrate	KNO_3	101.1032	2.400E-04	0.0485
Ferric sulfate	$Fe_2(SO_4)_3$	399.8800	6.250E-04	0.4999
Ferric chloride	$FeCl_3$	162.2000	7.667E-05	0.0249
Strontium Nitrate	$Sr(NO_3)_2$	211.6300	2.874E-06	0.0012
Sodium Metasilicate, 5-hydrate	$Na_2SiO_3.5H_2O$	212.1400	6.000E-04	0.2546
Magnesium Chloride	MgCl2	95.2110	3.100E-04	0.0590
Acetic Acid	$C_2H_4O_2$	60.0500	3.000E-04	0.0360

Appendix B

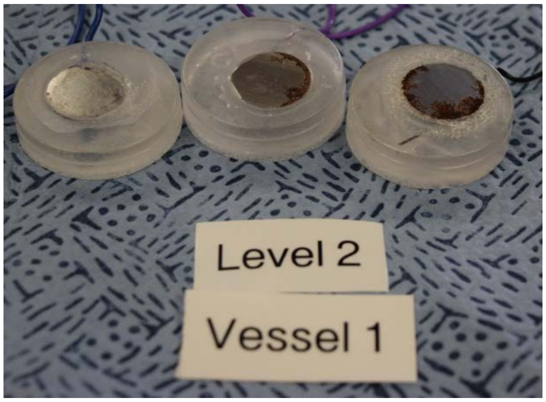
Pictures of Vapor Space Corrosion Samples after Test

Samples cold mounted

Vessel 1: Level 3
4 months

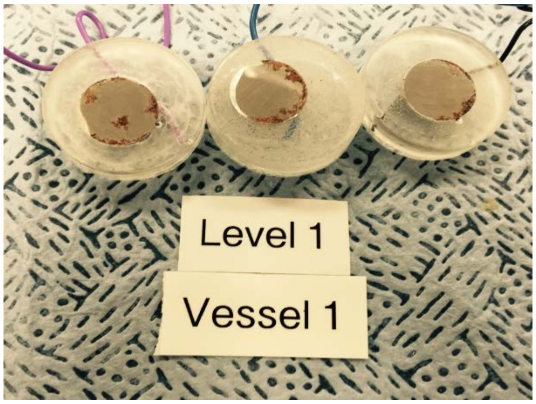


Vessel 1: Level 2
4 months

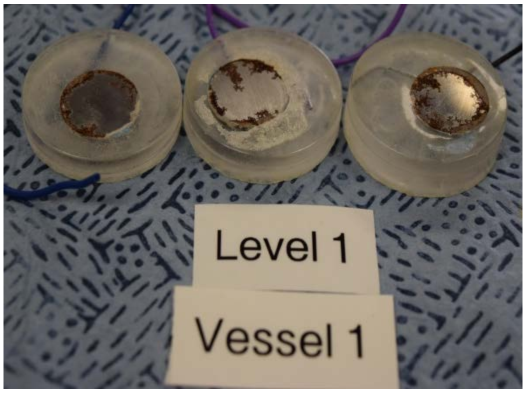


Vessel 1: Level 1

2 months



4 months



After removal of cold mount

Vessel 1: Level 3

Before cleaning

Front

Back

4 month

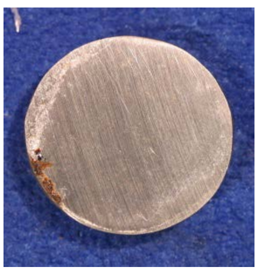
2315

A1

After cleaning

Front

Back



Front

Back

4 months

2316

B1

Front

Back

Front

Back

4 months

2317

C1

Front

Back

After removal of cold mount

Vessel 1: Level 2

Before cleaning | **After cleaning**

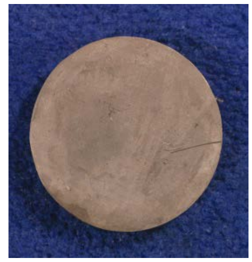

Front


Back

4 months

2315

A2


Front


Back


Front


Back

4 months

2316

B2


Front


Back


Front


Back

4 months

2317

C2


Front


Back

After removal of cold mount

Before cleaning

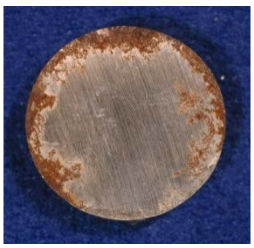
Vessel 1: Level 1

After cleaning


2 months

2315

A01


4 months

2315

A3



2 months

2316

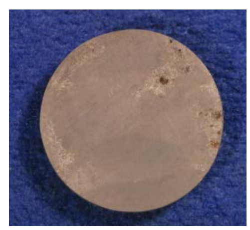
B01

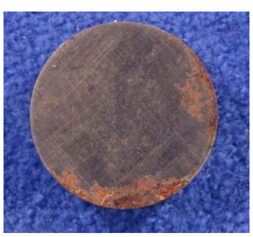


4 months

2316

B3




2 months

2317

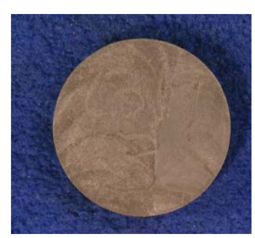
C01



4 months

2317

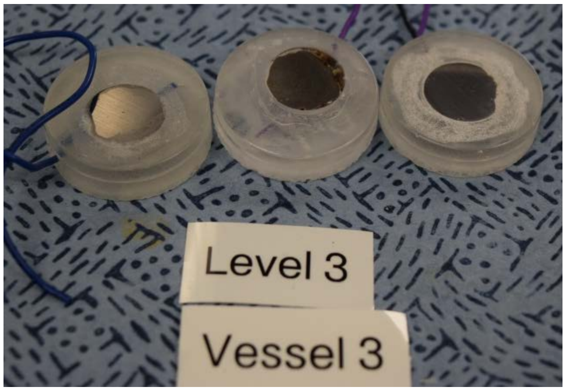
C3

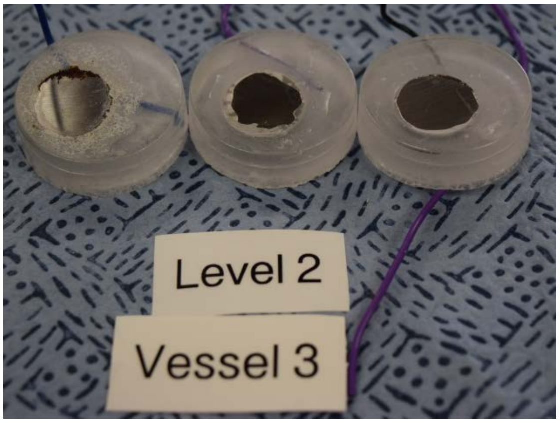
Front **Back** **Front** **Back**

Samples cold mounted

Vessel 3: Level 3
4 months

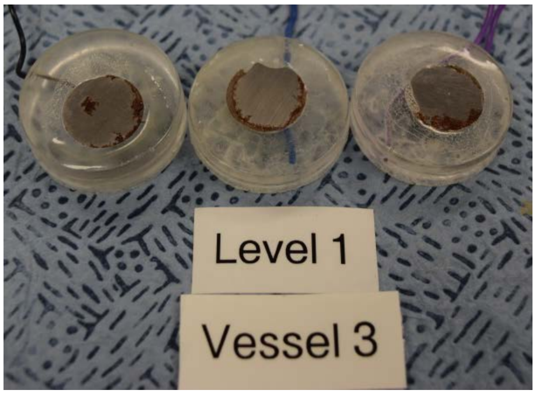


Vessel 3: Level 2
4 months

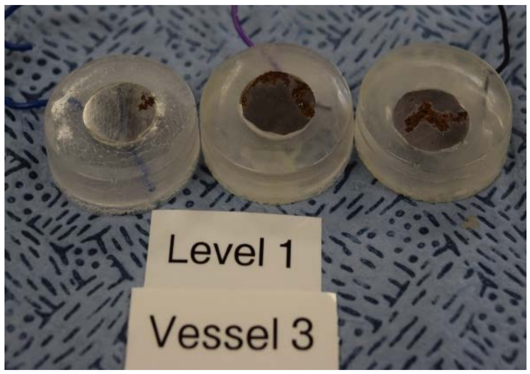


Vessel 3: Level 1

2 months



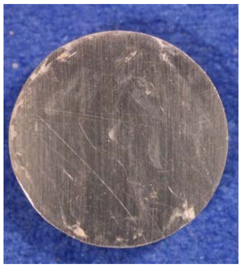
4 months



After removal of cold mount

Vessel 3: Level 3

Before cleaning | **After cleaning**


Front

Back

4 months

2315

A4


Front

Back


Front

Back

4 months

2316

B4


Front

Back


Front

Back

4 months

2317

C4


Front

Back

After removal of cold mount

Vessel 3: Level 2

Before cleaning

Front

Back

4 months

2315

A5

After cleaning

Front

Back

Front

Back

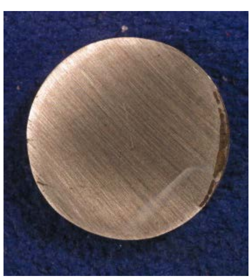
4 months

2316

B5

Front

Back



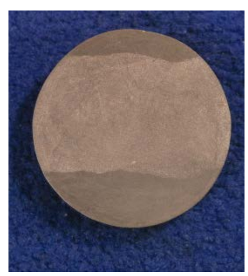
Front

Back

4 months

2317

C5



Front

Back

After removal of cold mount

Before cleaning

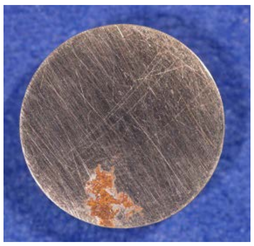
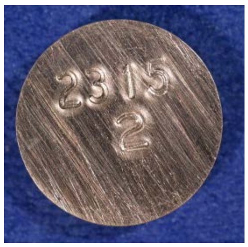
Vessel 3: Level 1

After cleaning


2 months

2315

A6

4 months

2315

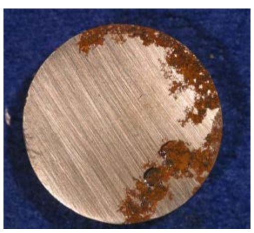
A02



2 months

2316

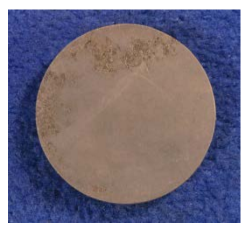
B02


4 months

2316

B6





2 months

2317

C02



4 months

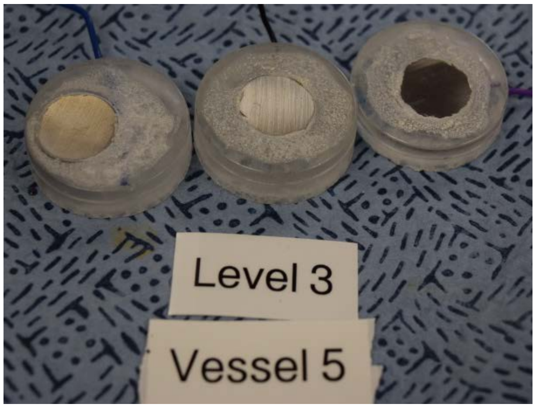
2317

C6

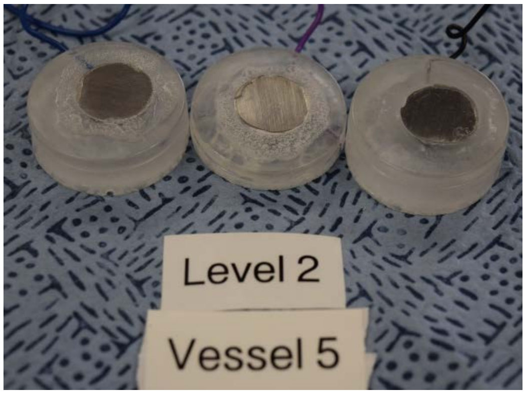

Front **Back** **Front** **Back**

Samples cold mounted

Vessel 5: Level 3
4 months

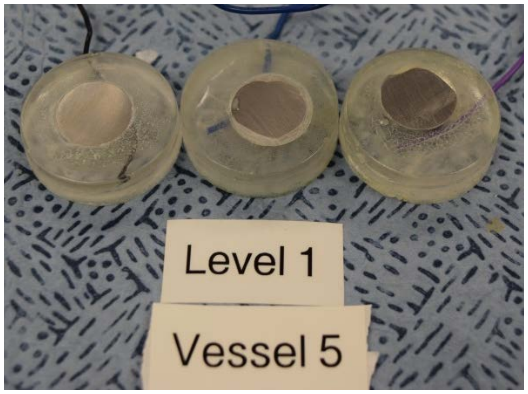


Vessel 5: Level 2
4 months

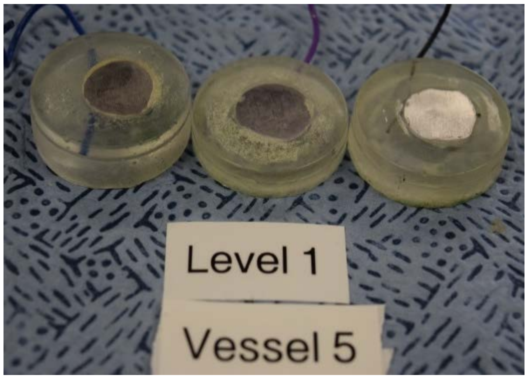


Vessel 5: Level 1

2 months



4 months



After removal of cold mount

Vessel 5: Level 3

Before cleaning | **After cleaning**


Front

Back

4 months

2315

A7


Front


Back


Front

Back

4 months

2316

B7


Front


Back


Front

Back

4 months

2317

C7


Front


Back

After removal of cold mount

Vessel 5: Level 2

Before cleaning | **After cleaning**


Front

Back

4 months

2315

A8


Front


Back


Front

Back

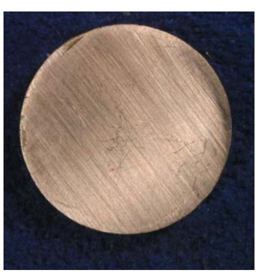
4 months

2316

B8


Front

Back


Front

Back

4 months

2317

C8


Front


Back

After removal of cold mount

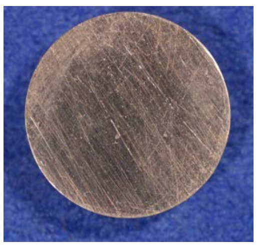
Vessel 5: Level 1

Before cleaning | **After cleaning**


2 months

2315

A9


4 months

2315

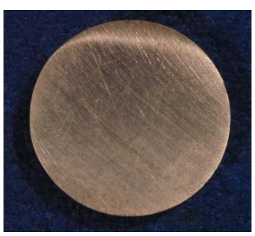
A03



2 months

2316

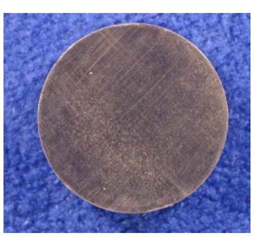
B03


4 months

2316

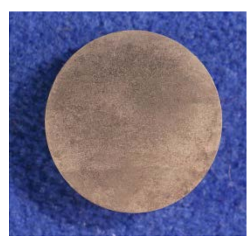
B9


2 months

2317

C03





4 months

2317

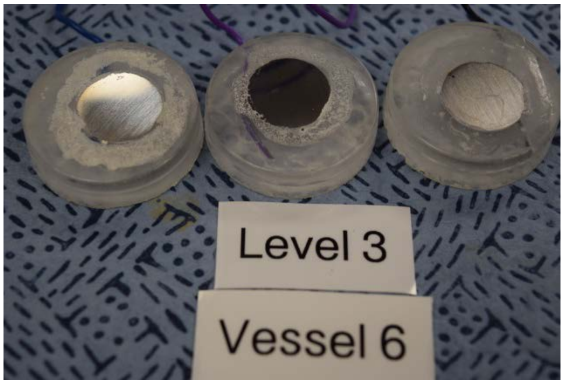
C9


Front **Back** **Front** **Back**

Samples cold mounted

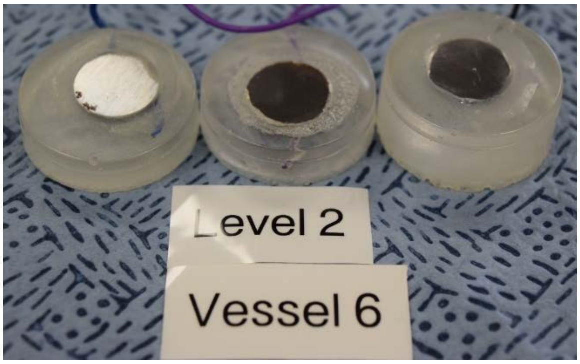
Vessel 6: Level 3

4 months



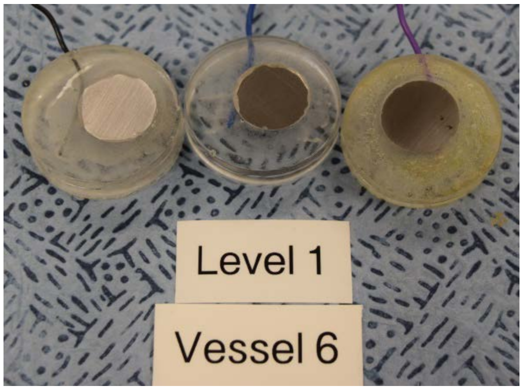
Vessel 6: Level 2

4 months

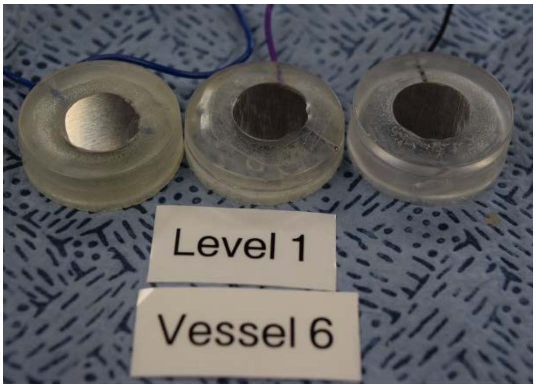


Vessel 6: Level 1

2 months



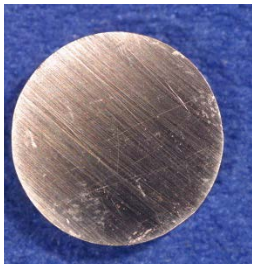
4 months



After removal of cold mount

4Vessel 6: Level 3

Before cleaning



Front

Back

4 months

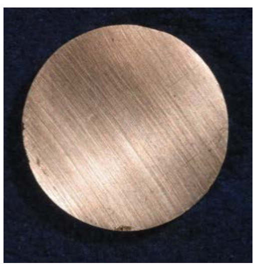
2315

A10

After cleaning

Front

Back



Front

Back

4 months

2316

B10

Front

Back

Front

Back

4 months

2317

C10

Front

Back

After removal of cold mount

Vessel 6: Level 2

Before cleaning | **After cleaning**

Front

Back

4 months

2315

A11

Front

Back

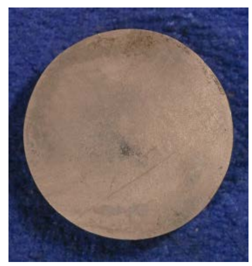
Front

Back

4 months

2316

B11



Front

Back

Front

Back

4 months

2317

C11

Front

Back

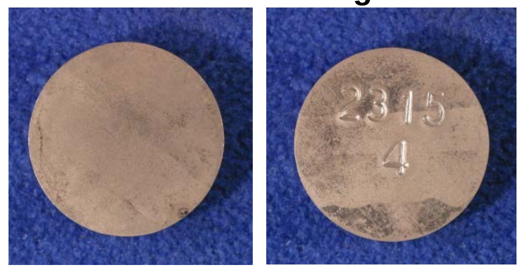
After removal of cold mount

Before cleaning | **Vessel 6: Level 1** | **After cleaning**

2 months

2315

A04



4 months

2315

A12

2 months

2316

B12

4 months

2316

B04

2 months

2317

C12

4 months

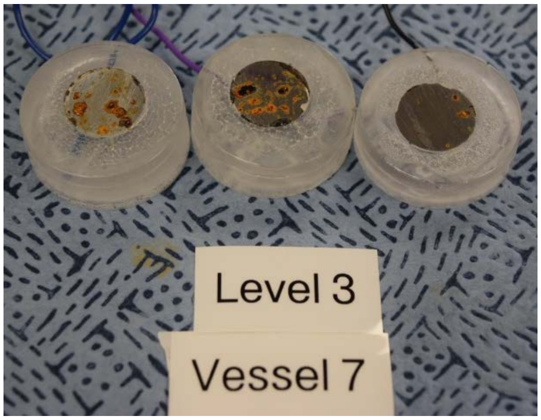
2317

C04

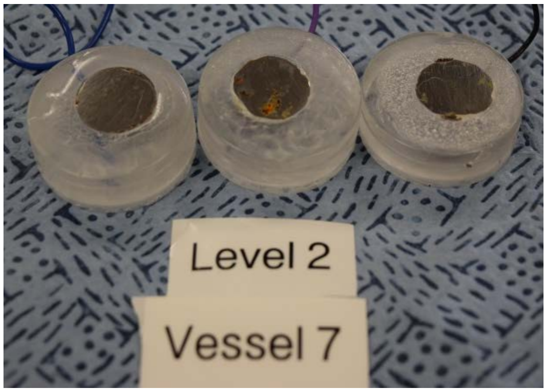
Front **Back** **Front** **Back**

Samples cold mounted

Vessel 7: Level 3
4 months

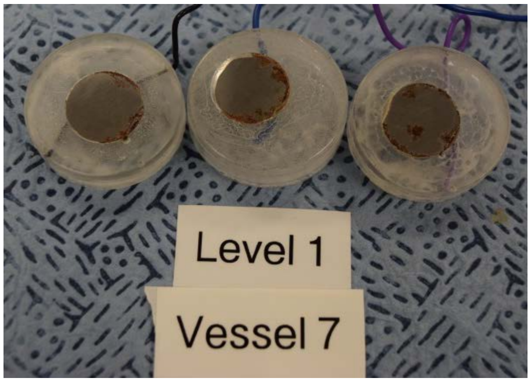


Vessel 7: Level 2
4 months

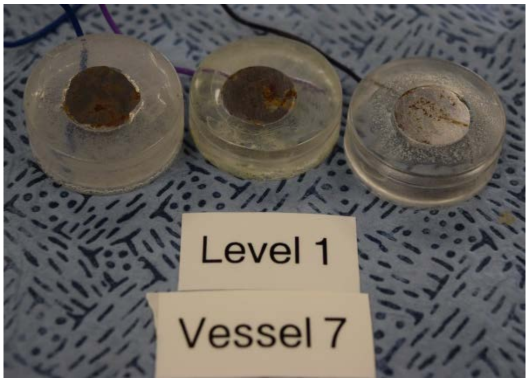


Vessel 7: Level 1

2 months



4 months



After removal of cold mount

Vessel 7: Level 3

Before cleaning

Front **Back**

4 months

2315

A05

After cleaning

Front **Back**

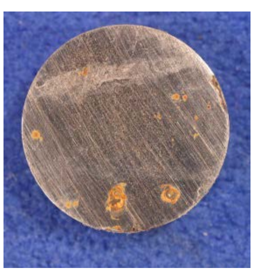
Front **Back**

4 months

2316

B05

Front **Back**



Front **Back**

4 months

2317

C05

Front **Back**

After removal of cold mount

Vessel 7: Level 2

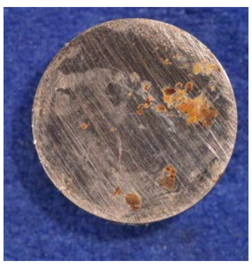
Before cleaning | **After cleaning**

4 months

2315

A06

Front **Back** **Front** **Back**



4 months

2316

B06

Front **Back** **Front** **Back**

4 months

2317

C06

Front **Back** **Front** **Back**

After removal of cold mount

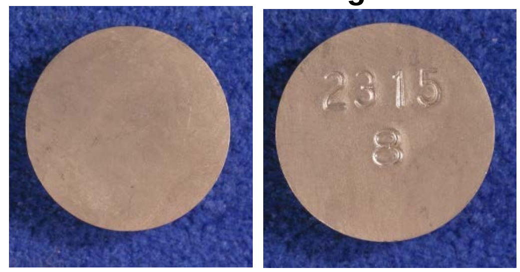
Vessel 7: Level 1

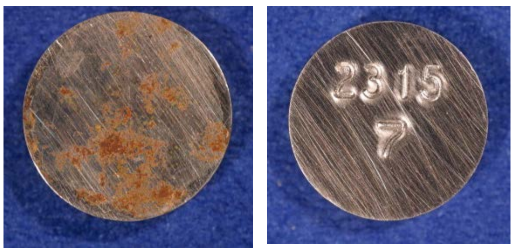
Before cleaning | **After cleaning**

2 months

2315

A08





4 months

2315

A07

2 months

2316

B08

4 months

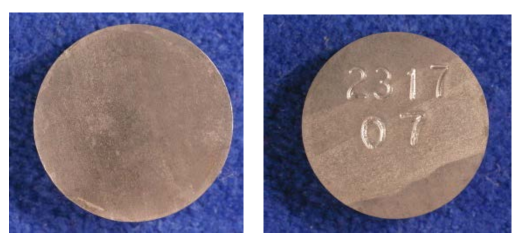
2316

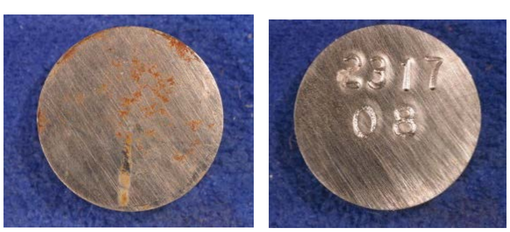
B07

2 months

2317

C07





4 months

2317

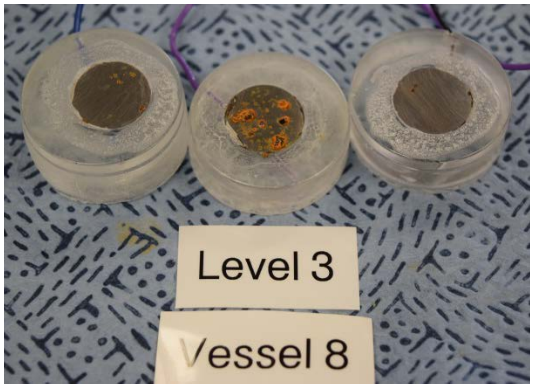
C08

Front **Back** | **Front** **Back**

Samples cold mounted

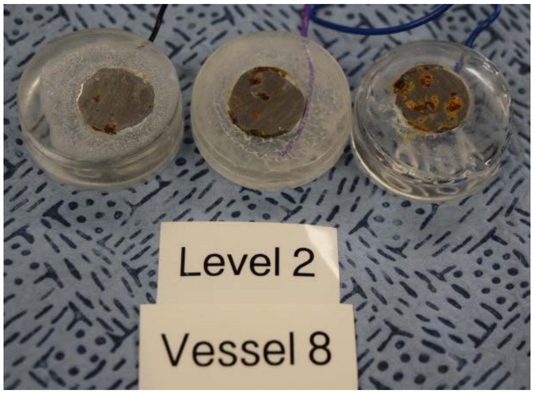
Vessel 8: Level 3

4 months



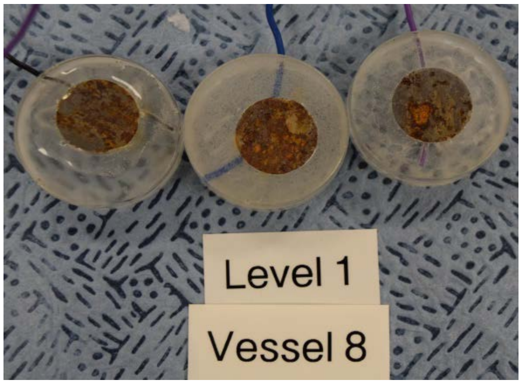
Vessel 8: Level 2

4 months

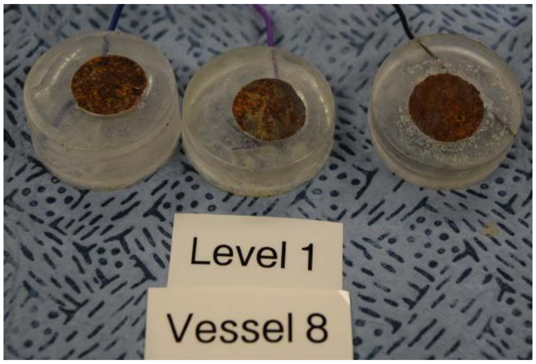


Vessel 8: Level 1

2 months



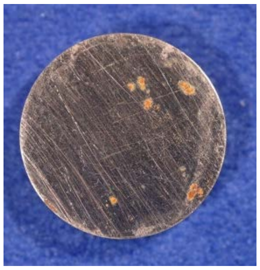
4 months



After removal of cold mount

Vessel 8: Level 3

Before cleaning | **After cleaning**


Front

Back

4 months

2315

A09


Front

Back


Front

Back

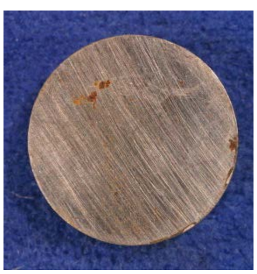
4 months

2316

B09


Front

Back


Front

Back

4 months

2317

C09

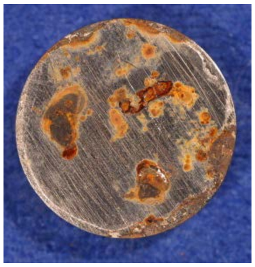

Front

Back

After removal of cold mount

Vessel 8: Level 2

Before cleaning



Front

Back

4 months

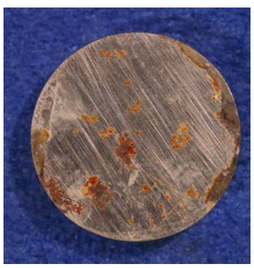
2315

A010

After cleaning

Front

Back



Front

Back

4 months

2316

B010

Front

Back

Front

Back

4 months

2317

C010

Front

Back

After removal of cold mount

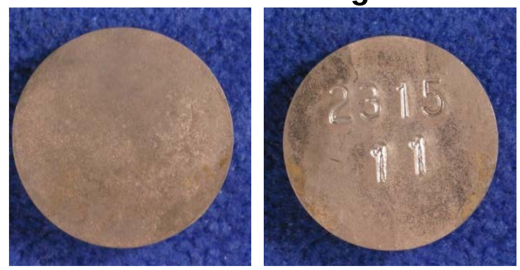
Vessel 8: Level 1

Before cleaning | **After cleaning**

2 months

2315

A011



4 months

2315

A012

2 months

2316

B012

4 months

2316

B011

2 months

2317

C011

4 months

2317

C012

Front **Back** | **Front** **Back**

Appendix D

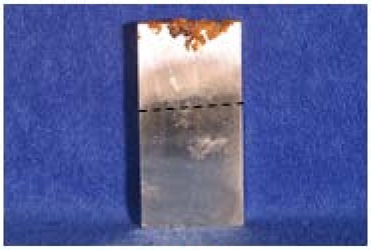
Pictures of Liquid Air Interface and Total Immersion Corrosion Samples after Test

Solution 1

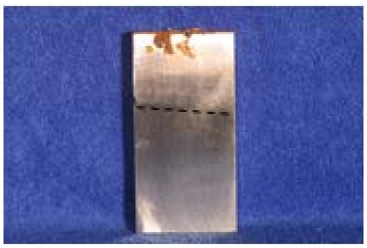
4 months exposure

A1

Before cleaning

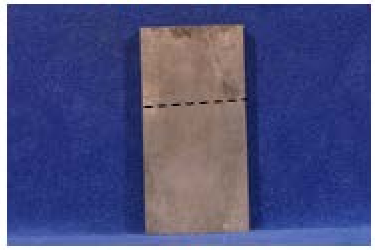


Front side

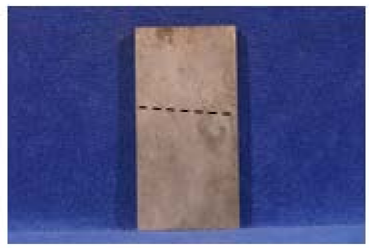


Back side

After cleaning



Front side

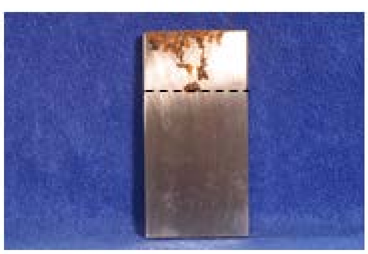


Back side

B1

Before cleaning

Front side



Back side

After cleaning

Front side

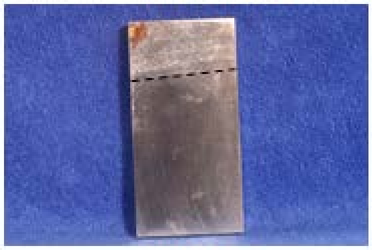
Back side

Solution 1

4 months exposure

C1

Before cleaning

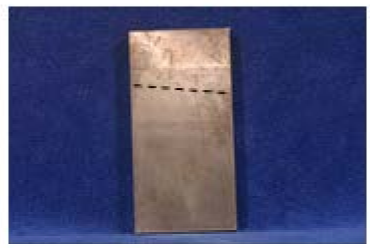


Front side

Back side

After cleaning

Front side



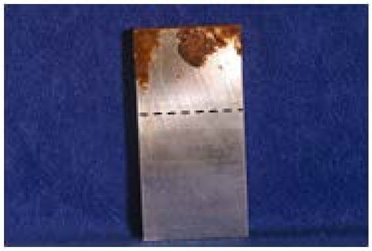
Back side

Solution 2

4 months exposure

A2

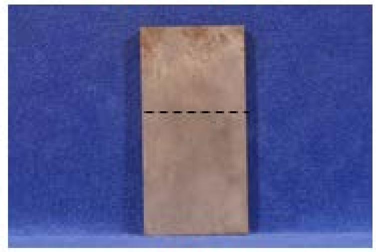
Before cleaning



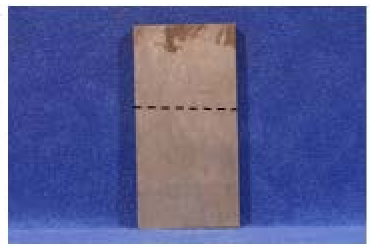
Front side

Back side

After cleaning



Front side



Back side

B2

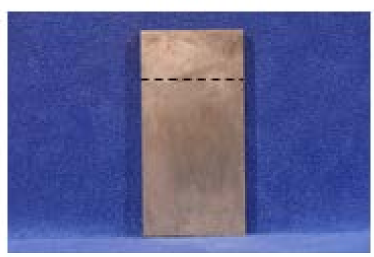
Before cleaning

Front side

Back side

After cleaning

Front side



Back side

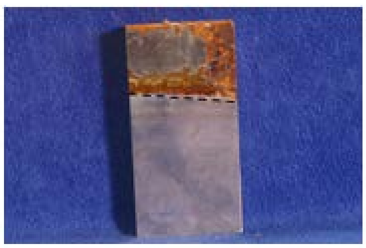
Solution 2

4 months exposure

C2

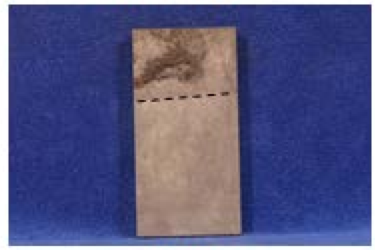
Before cleaning

Front side

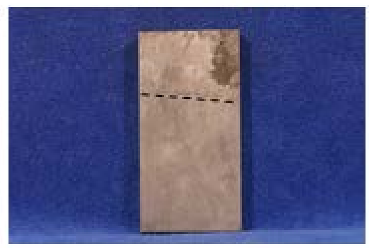


Back side

After cleaning



Front side



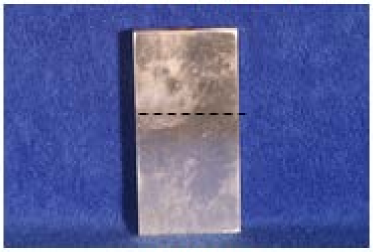
Back side

Solution 3

4 months exposure

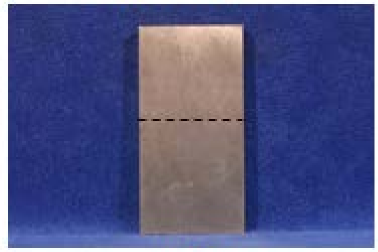
A3

Before cleaning

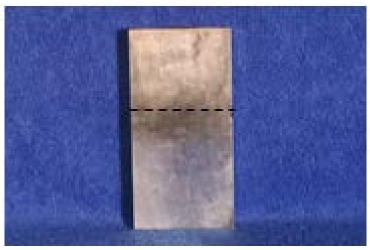


Front side

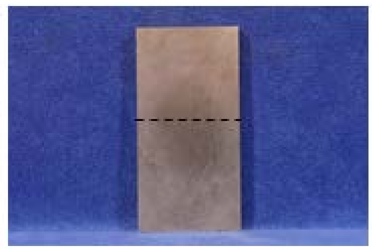
After cleaning



Front side



Back side



Back side

B3

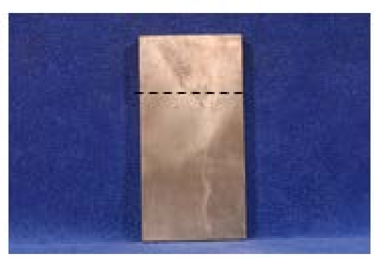
Before cleaning

Front side

After cleaning

Front side

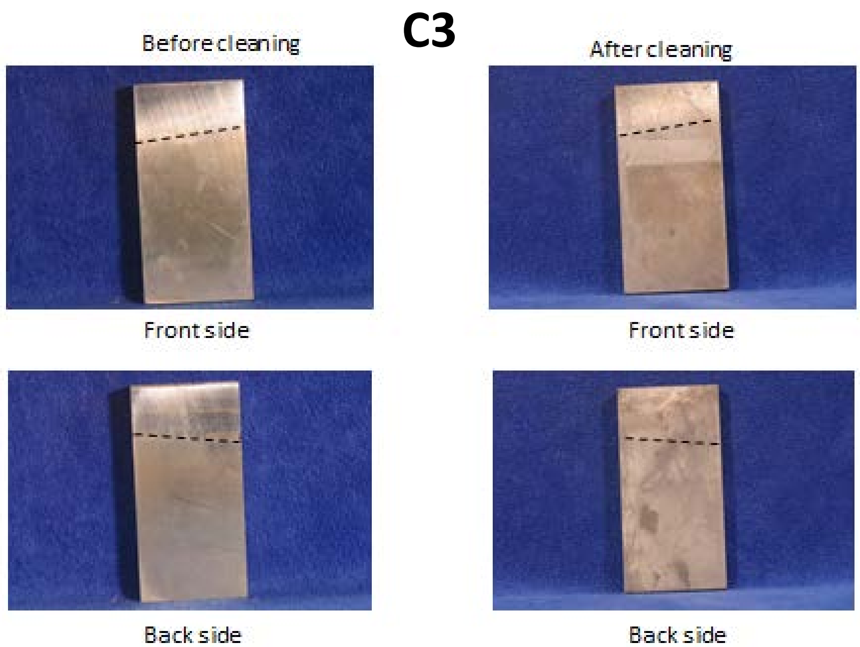
Back side



Back side

Solution 3

4 months exposure

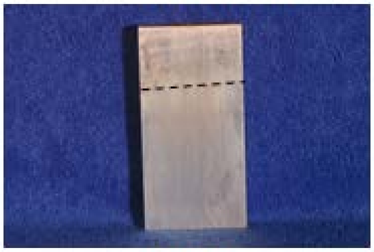


Solution 4

4 months exposure

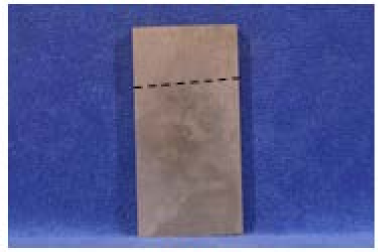
A4

Before cleaning

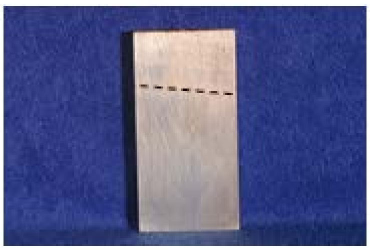


Front side

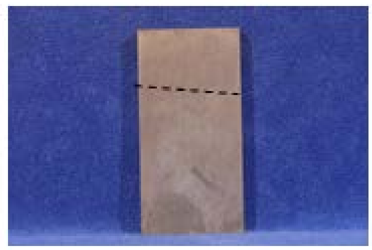
After cleaning



Front side



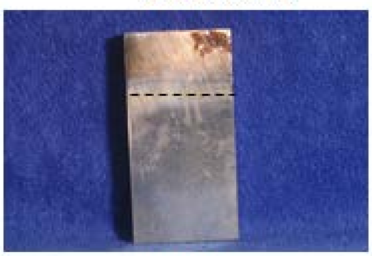
Back side



Back side

B4

Before cleaning

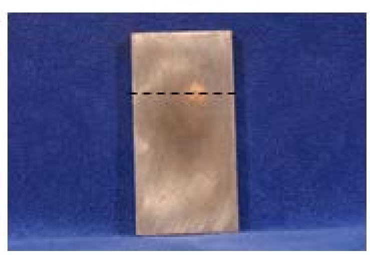


Front side

After cleaning

Front side

Back side



Back side

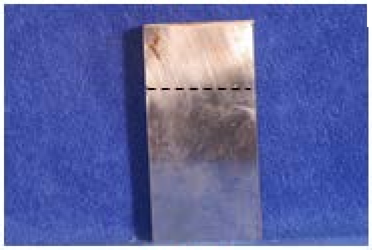
Solution 4

4 months exposure

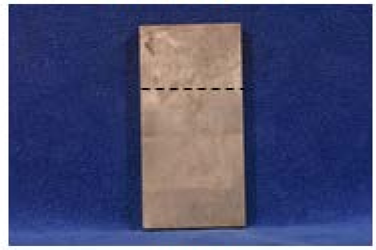
Before cleaning

C4

After cleaning



Front side



Front side

Back side

Back side

Solution 5

2 months exposure

A5

Before cleaning

Front side

After cleaning

Front side

Back side

Back side

4 months exposure

A6

Before cleaning

Front side

After cleaning

Front side

Back side

Back side

Solution 5

2 months exposure

B5

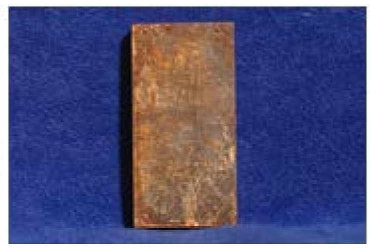
Before cleaning

Front side

After cleaning

Front side

Back side



Back side

4 months exposure

B6

Before cleaning

Front side

After cleaning

Front side

Back side

Back side

Solution 5

2 months exposure

C5

Before cleaning

Front side

After cleaning

Front side

Back side

Back side

4 months exposure

C6

Before cleaning

Front side

After cleaning

Front side

Back side

Back side

Solution 6

2 months exposure

A7

Before cleaning

Front side

Back side

After cleaning

Front side

Back side

4 months exposure

A8

Before cleaning

Front side

Back side

After cleaning

Front side

Back side

Solution 6

2 months exposure

B7

Before cleaning

Front side

Back side

After cleaning

Front side

Back side

4 months exposure

B8

Before cleaning

Front side

Back side

After cleaning

Front side

Back side

Solution 6

2 months exposure

Before cleaning **C7** After cleaning

Front side

Front side

Back side

Back side

4 month exposure

Before cleaning **C8** After cleaning

Front side

Front side

Back side

Back side

Appendix C

Chemical Composition of Simulants used in Liquid Air Interface and Total Immersion Corrosion Testing

Composition of simulant for LAI-Solution 1

Temperature: 40 °C
Volume: 2 L

Simulant Source	Formula	Weigh required (g)	weight obtained (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	0.0375	0.0374
Sodium chloride	NaCl	0.2922	0.2924
Sodium fluoride	NaF	0.0630	0.0633
Sodium sulfate	Na_2SO_4	0.3551	0.3553
Sodium hydroxide	NaOH	0.7999	0.8002
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	0.0950	0.0953
Sodium carbonate	Na_2CO_3	21.1977	21.1978
Sodium nitrate	$NaNO_3$	16.9989	16.9987
Sodium nitrite	$NaNO_2$	6.8995	6.8993

pH after mixing: 11.33
Normalize pH 12.01 (required a pH of 12)

Composition of simulant for LAI-Solution 2

Temperature: 40 °C
Volume: 2 L

Simulant Source	Formula	Weight required (g)	weight obtained (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	0.1501	0.1501
Sodium chloride	NaCl	1.1688	1.1689
Sodium fluoride	NaF	0.2519	0.2518
Sodium sulfate	Na_2SO_4	1.4204	4.4202
Sodium hydroxide	NaOH	0.7999	0.8004
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	0.3801	0.3803
Sodium carbonate	Na_2CO_3	21.1977	21.1979
Sodium nitrate	$NaNO_3$	84.9947	84.9947
Sodium nitrite	$NaNO_2$	10.3493	10.3494

pH after mixing: 11.57
Normalize pH: 12.01 (required a pH of 12)

Composition of simulant for LAI-Solution 3

Temperature: 40 °C
Volume: 2 L

Simulant Source	Formula	Weight required (g)	weight obtained (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	0.1501	0.1502
Sodium chloride	$NaCl$	1.1688	1.1685
Sodium fluoride	NaF	0.2519	0.2519
Sodium sulfate	Na_2SO_4	1.4204	1.4202
Sodium hydroxide	$NaOH$	0.7999	0.8001
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	0.3801	0.3799
Sodium carbonate	Na_2CO_3	21.1977	24.8003
Sodium nitrate	$NaNO_3$	84.9947	84.9946
Sodium nitrite	$NaNO_2$	114.5322	114.5324

pH after mixing: 11.55
Normalize pH 12.01 (required a pH of 12)

Composition of simulant for LAI-Solution 4

Temperature: 40 °C
Volume: 2 L

Simulant Source	Formula	Weight required (g)	weight obtained (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	0.7503	0.7505
Sodium chloride	$NaCl$	2.3376	2.3377
Sodium fluoride	NaF	0.4199	0.4198
Sodium sulfate	Na_2SO_4	7.1020	7.1017
Sodium hydroxide	$NaOH$	0.7999	0.8002
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	3.8012	3.801
Sodium carbonate	Na_2CO_3	52.9943	61.9998
Sodium nitrate	$NaNO_3$	169.9894	169.9894
Sodium nitrite	$NaNO_2$	229.0644	229.0646

pH after mixing: 11.35
Normalize pH 12 (required a pH of 12)

Composition of simulant for LAI-Solution 5 (LDP)

Temperature: 45 °C
Volume: 2 L

Simulant Source	Formula	Weight required (g)	weight obtained (g)
Sodium bicarbonate	$NaHCO_3$	0.1882	0.1883
Calcium hydroxide	$Ca(OH)_2$	0.0179	0.0179
Potassium nitrate	KNO_3	0.0136	0.0135
Magnesium Nitrate, 6-hydrate	$Mg(NO_3)_2.6H_2O$	0.0078	0.0078
Strontium Nitrate	$Sr(NO_3)_2$	0.0017	0.0018
Sodium sulfate	Na_2SO_4	0.0005	0.0007
Sodium Metasilicate, 5-hydrate	$Na_2SiO_3.5H_2O$	0.0194	0.0193
Ferric chloride	$FeCl_3$	0.0009	0.0008
Manganese Nitrate	$Mn(NO_3)_2$	0.0001	0.0002
Acetic Acid	$C_2H_4O_2$	0.0360	0.0363

pH after mixing: 6.22
Normalize pH 7.64 (required a pH of 7.6)

Composition of simulant for LAI-Solution 6 (GW)

Temperature: 45 °C
Volume: 2 L

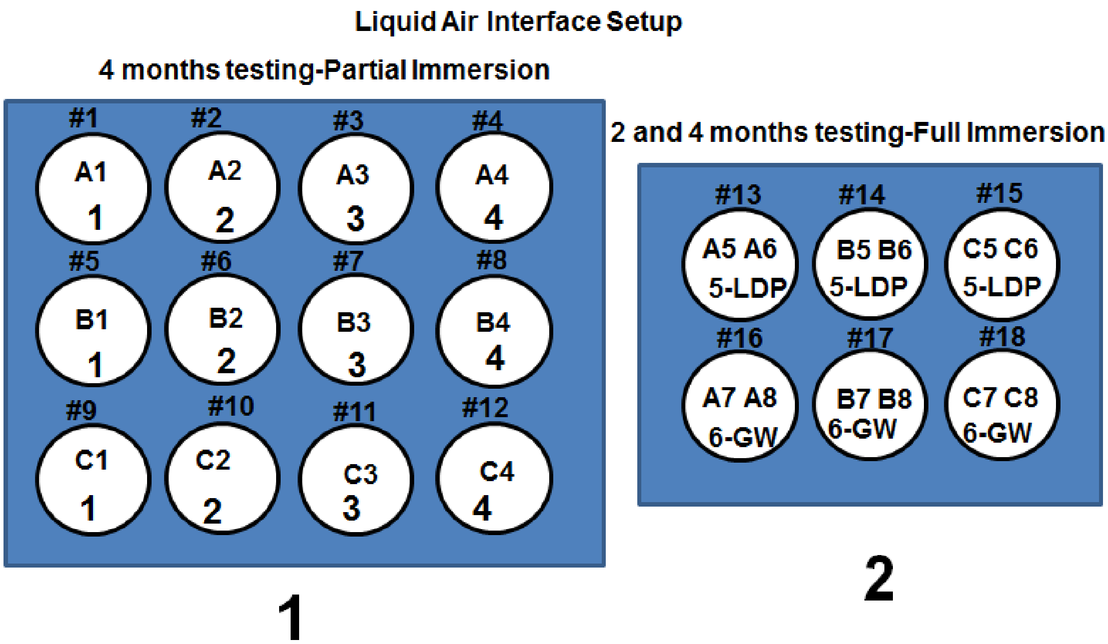
Simulant Source	Formula	Weight required (g)	weight obtained (g)
Sodium bicarbonate	$NaHCO_3$	0.2940	0.2943
Calcium hydroxide	$Ca(OH)_2$	0.2223	0.2221
Potassium nitrate	KNO_3	0.0485	0.0485
Ferric sulfate	$Fe_2(SO_4)_3$	0.4999	0.4997
Ferric chloride	$FeCl_3$	0.0249	0.0249
Strontium Nitrate	$Sr(NO_3)_2$	0.0012	0.0015
Sodium Metasilicate, 5-hydrate	$Na_2SiO_3.5H_2O$	0.2546	0.2544
Magnesium Chloride	MgCl2	0.0590	0.0591
Acetic Acid	$C_2H_4O_2$	0.0360	0.0364

pH after mixing: 6.83
Normalize pH 7.74 (required a pH of 7.6)

Appendix E

Open Circuit Potential, pH and Temperature vs. Time plots for LAI and TI Solutions

Diagram of Liquid-Air Interface Setup

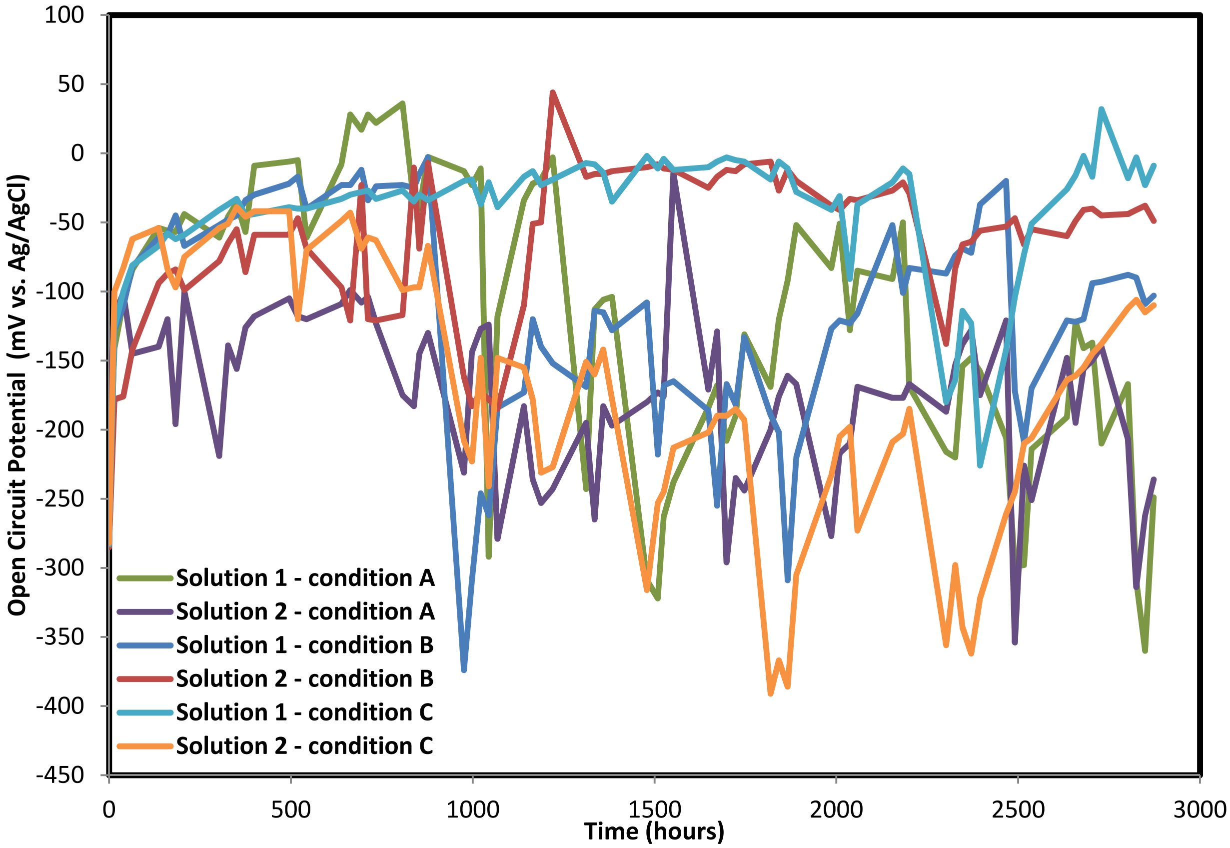


A	**DNV #2315**	Welded DNV #2232 and heat treated to 1200°F
B	**DNV#2316**	Welded DNV #2232 and heat treated to 1600°F
C	**DNV#2317**	Welded DNV #2232 with no heat treatment

Solution 1 and 2

4 month exposure

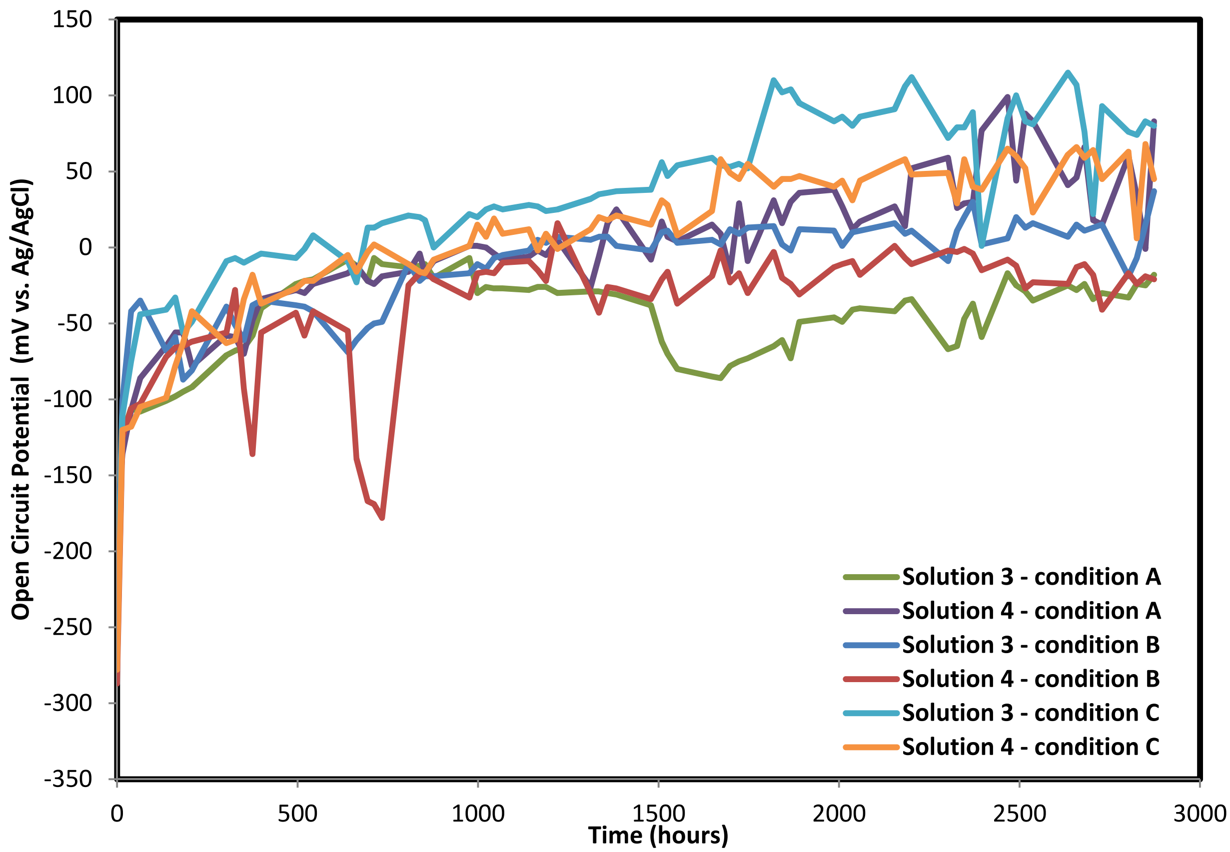
Open circuit potential vs. Time



Solution 3 and 4

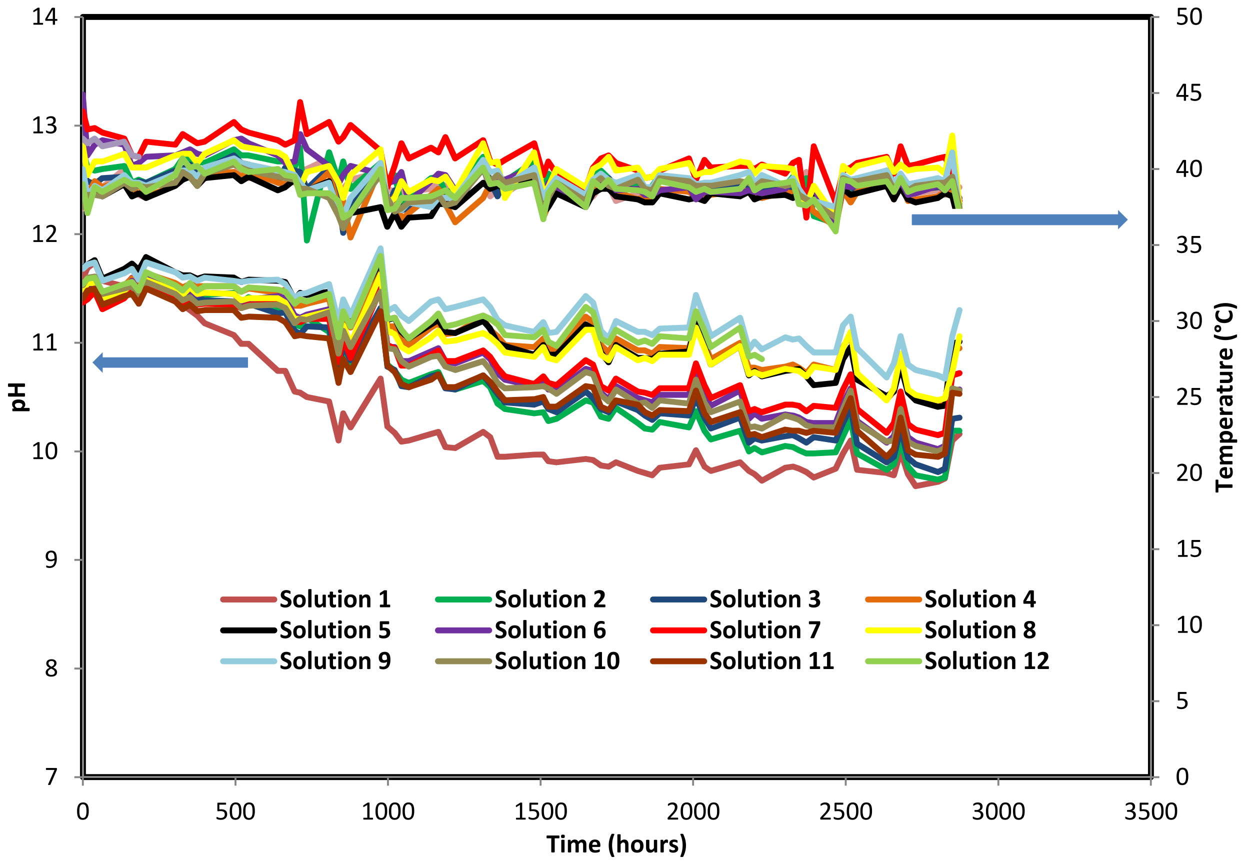
4 month exposure

Open circuit potential vs. Time



Solutions 1 to 12

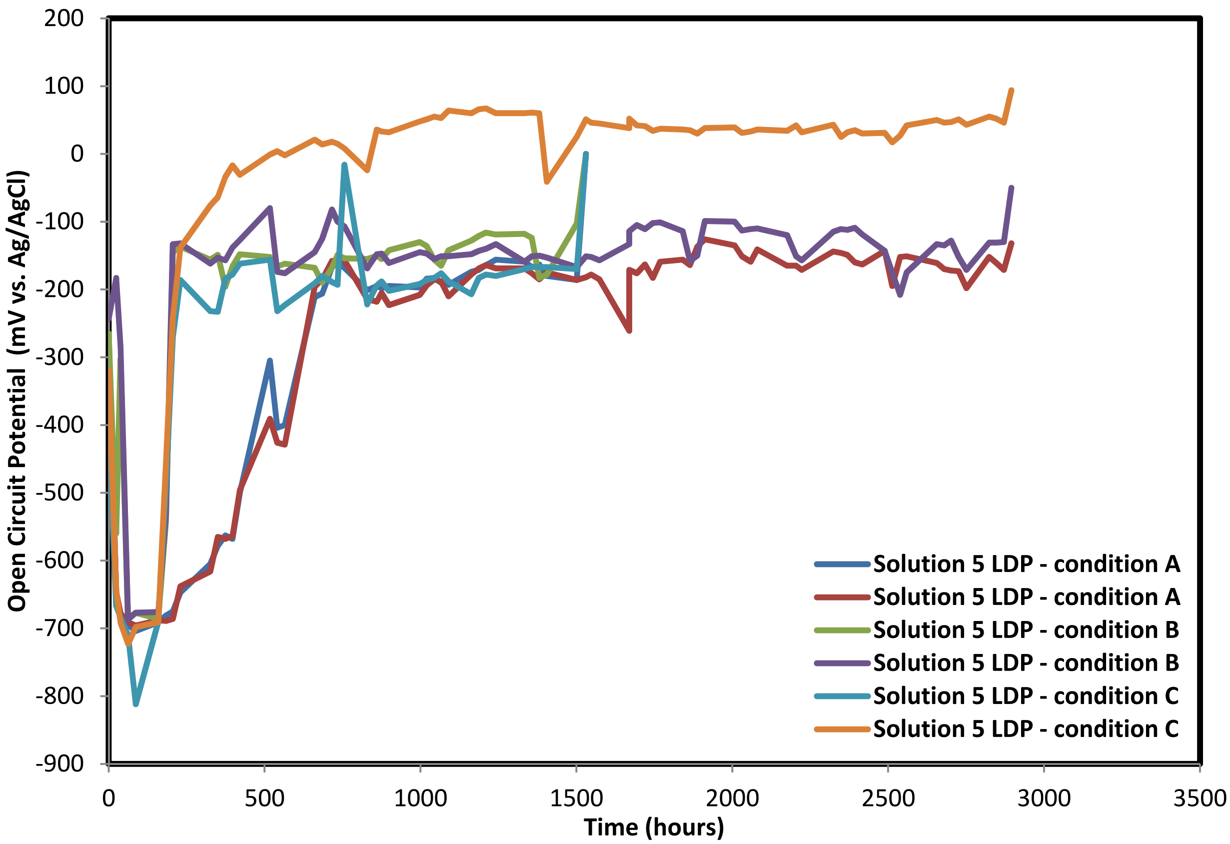
pH and Temperature vs. Time



Solution 5 - LDP

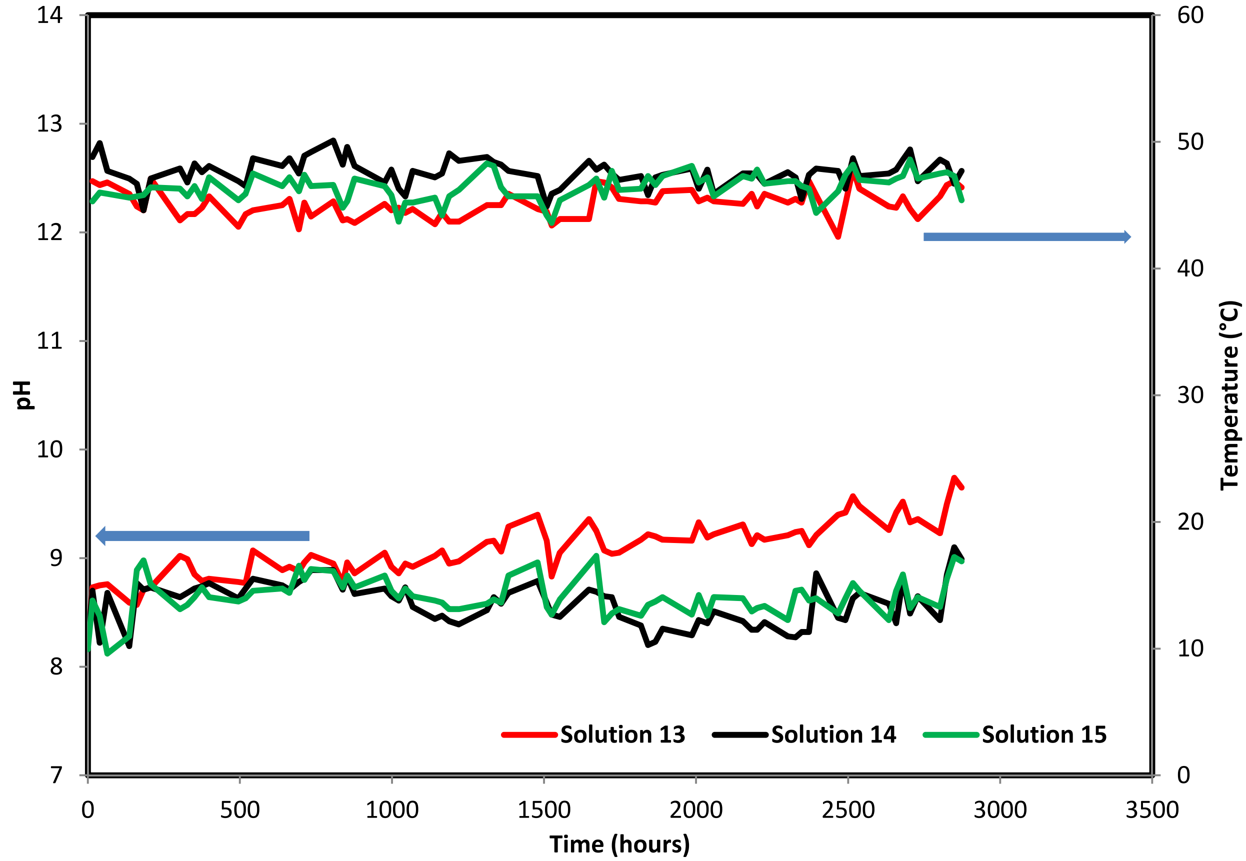
2 and 4 months exposure

Open circuit potential vs. Time



Solution 5 - LDP

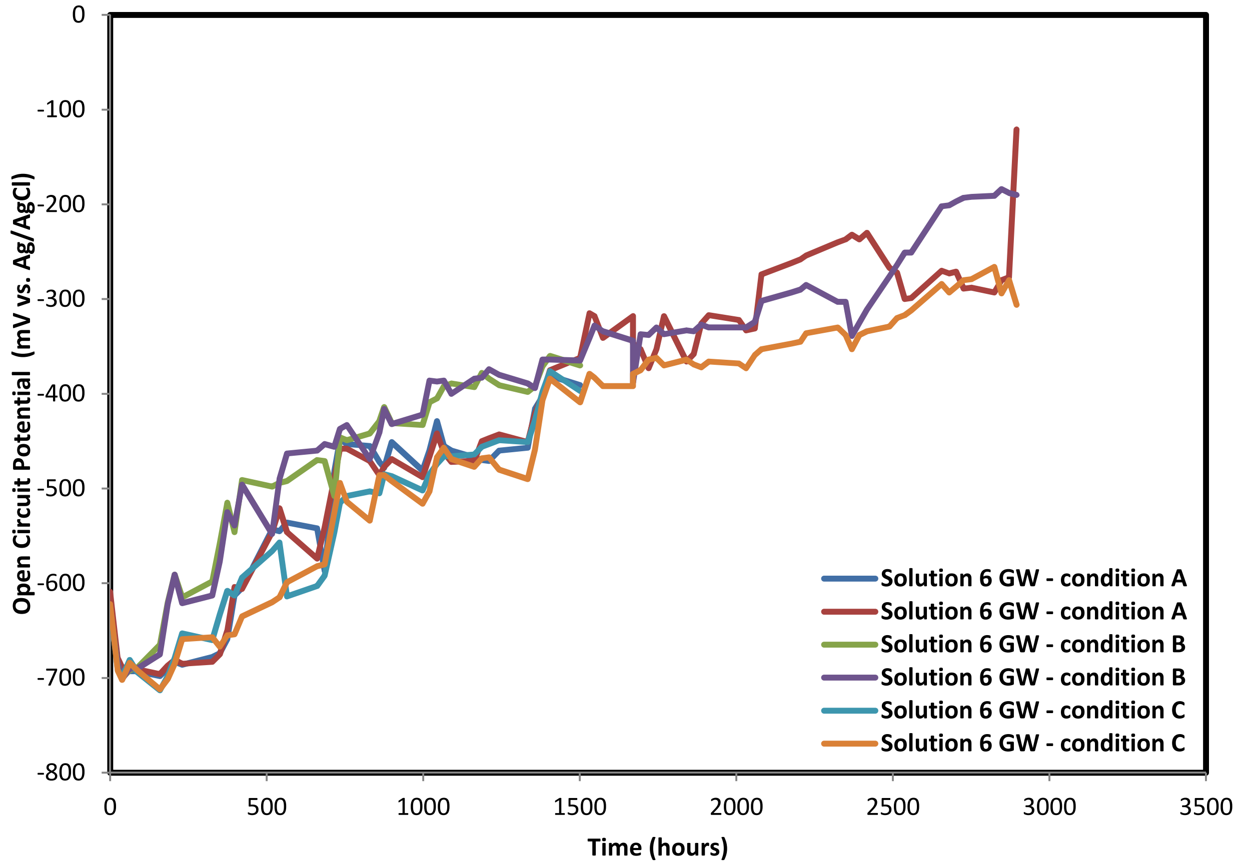
pH and Temperature vs. Time



Solution 6 - GW

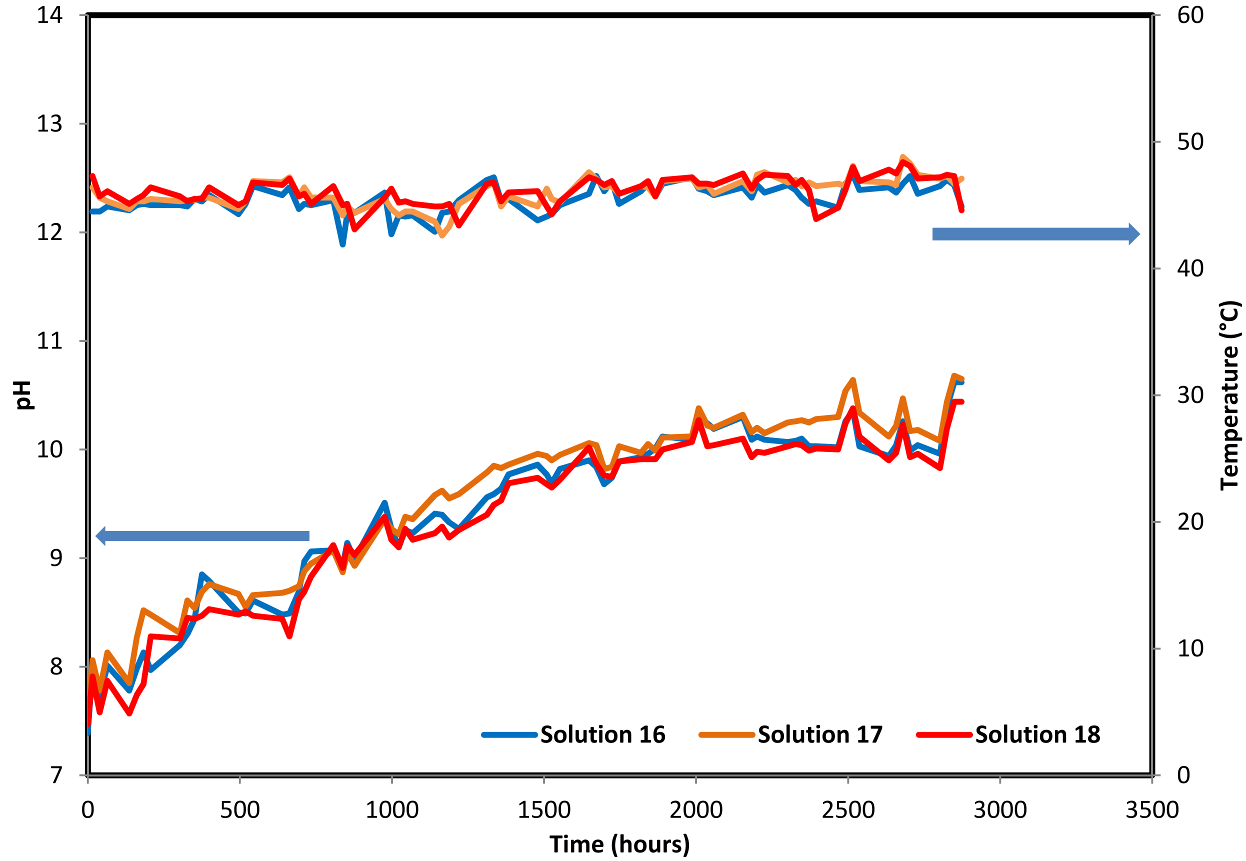
2 and 4 month exposure

Open circuit potential vs. Time



Solution 6 - GW

pH and Temperature vs. Time



Appendix F

Chemical Composition of Simulants used in Pitting Corrosion (Task 3) with Electrochemical Results and Pictures after Test

Pitting Corrosion Test Solutions

Temperature **40℃**

Material **TCR 128, Carbon Steel**

Test	NaOH	$NaNO_2$	Citrate	Na_2CrO_4	$NaNO_3$	NaCl	NaF	Na_2SO_4	Na_2CO_3	Na_3PO_4	pH
1	0	0.5	0.6	0.0001	0.1	0.01	0.003	0.1	0.2	0.0005	11.57
2	0	0.5	0.04	0.1	0.1	0.01	0.02	0.005	0.2	0.05	11.45
3	0	0.02	0.04	0.1	0.1	0.06	0.02	0.1	0.02	0.0005	11.08
4	0	0.02	0.04	0.1	0.1	0.4	0.003	0.005	0.02	0.0005	10.84
5	0	0.5	0.6	0.0001	0.1	0.4	0.003	0.1	0.2	0.05	11.3
6	0	0.1	0.6	0.1	0.1	0.4	0.05	0.1	0.02	0.0005	10.77
7	0.01	0.1	0.6	0.1	0.1	0.06	0.003	0.1	0.02	0.05	11.87
8	0.01	0.1	0.6	0.005	0.7	0.06	0.05	0.005	0.2	0.05	11.88
9	0.01	0.02	0.04	0.1	0.7	0.06	0.05	0.1	0.2	0.05	11.7
10	0.01	0.5	0.6	0.005	0.1	0.4	0.02	0.005	0.02	0.0005	12.12
11	0.01	0.1	0.04	0.005	0.7	0.01	0.003	0.005	0.02	0.0005	13.15
12	0.1	0.02	0.04	0.005	0.1	0.01	0.05	0.005	0.02	0.05	13.06
13	0.1	0.5	0.6	0.005	0.1	0.01	0.02	0.1	0.02	0.0005	13.03
14	0.1	0.1	0.6	0.005	0.1	0.06	0.05	0.005	0.2	0.05	13.15
15	0.1	0.02	0.04	0.005	0.1	0.4	0.003	0.1	0.2	0.0005	13.166
16	0.1	0.5	0.6	0.1	0.1	0.4	0.003	0.005	0.02	0.0005	12.98
17	0.1	0.02	0.04	0.005	0.1	0.4	0.02	0.1	0.02	0.05	12.92
18	0.1	0.5	0.6	0.1	0.7	0.4	0.02	0.1	0.2	0.05	13.03
19	0.01	0.1	0.04	0	0.5	0.06	0.003	0.005	0.02	0.01	12
20	0.01	0.5	0.04	0	0.5	0.06	0.01	0.1	0.2	0.005	12
21	0.01	1	0.04	0	0.5	0.4	0.003	0.005	0.2	0.005	12
22	0.01	0.5	0.04	0	1	0.06	0.01	0.005	0.02	0.01	12
23	0.01	1	0.04	0	1	0.06	0.003	0.1	0.02	0.005	12

Pitting Corrosion Test Solutions

Temperature **40℃**

Material **TCR 128, Carbon Steel**

Test	NaOH	$NaNO_2$	Citrate	Na_2CrO_4	$NaNO_3$	NaCl	NaF	Na_2SO_4	Na_2CO_3	Na_3PO_4	pH
24	0.01	1.5	0.04	0	1	0.4	0.01	0.1	0.2	0.01	12
25	0.01	1	0.04	0	1.5	0.06	0.003	0.1	0.2	0.005	12
26	0.01	1.5	0.04	0	1.5	0.4	0.003	0.005	0.02	0.01	12
27	0.01	2	0.04	0	1.5	0.4	0.01	0.005	0.2	0.01	12
28	0.01	1	0.04	0	2	0.06	0.01	0.1	0.2	0.005	12
29	0.01	1.5	0.04	0	2	0.4	0.01	0.005	0.02	0.01	12
30	0.01	2	0.04	0	2	0.06	0.003	0.1	0.02	0.005	12

SRNL

Pitting Corrosion Testing, Task 3

Test ID **1**

This formula will make **1.4** Liters

Date: 2/11/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	0.1764	0.1773
3	Sodium Chloride	0.8182	0.8174
4	Sodium Nitrite	48.2965	48.2953
5	Sodium Sulfate	19.8982	19.8432
6	Sodium Phosphate, Tribasic 12	0.2661	0.2643
7	Sodium Carbonate	29.6772	29.6774
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6215
9	Sodium Chromate	0.0227	0.0219
10	Sodium Nitrate	11.8993	11.8971

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.6

Record pH: 11.58 Temp: °C

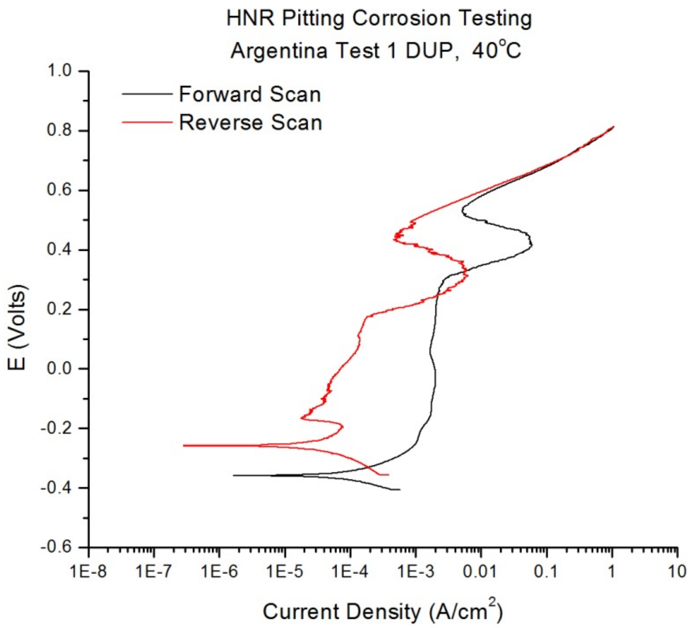
Comments/Notes:

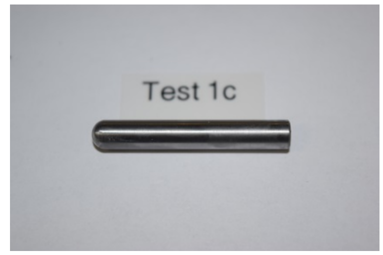
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	Test 1C10	2/11/16

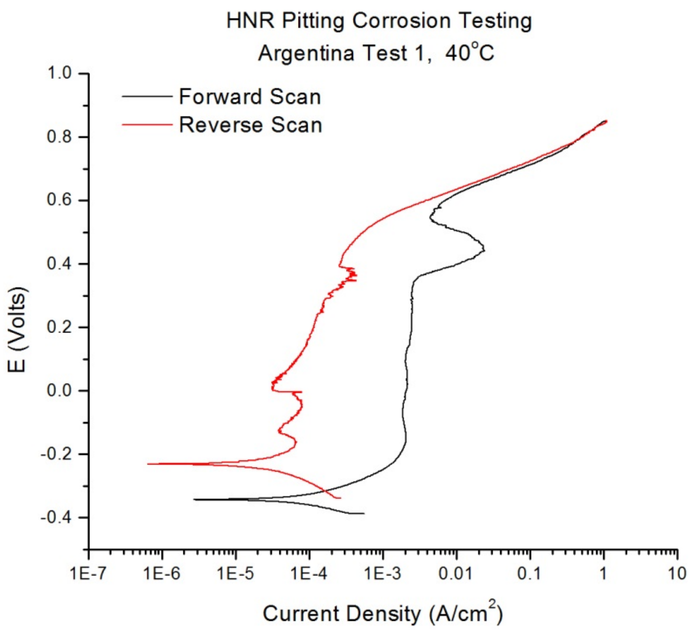
Prepared by: Matt VS Date: 2/11/16 Reviewer: [signature]

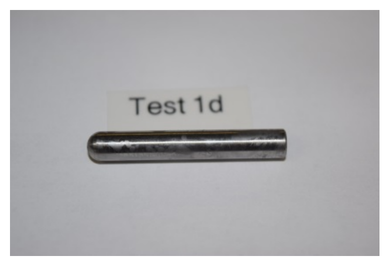
Date Printed(2/11/2016

Cyclic Potentiodynamic Polarization Test 1









SRNL

Pitting Corrosion Testing, Task 3

Test ID **2**

This formula will make **1.4** Liters

Date: 2/02/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	1.1757	1.1748
3	Sodium Chloride	0.8182	0.8215
4	Sodium Nitrite	48.2965	48.2952
5	Sodium Sulfate	0.9949	0.9973
6	Sodium Phosphate, Tribasic 12	26.6084	26.6032
7	Sodium Carbonate	29.6772	29.6416
8	Sodium Citrate	14.6222	14.6158
9	Sodium Chromate	22.6842	22.6635
10	Sodium Nitrate	11.8993	11.8773

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.4500

Record pH: 11.11 Temp: °C

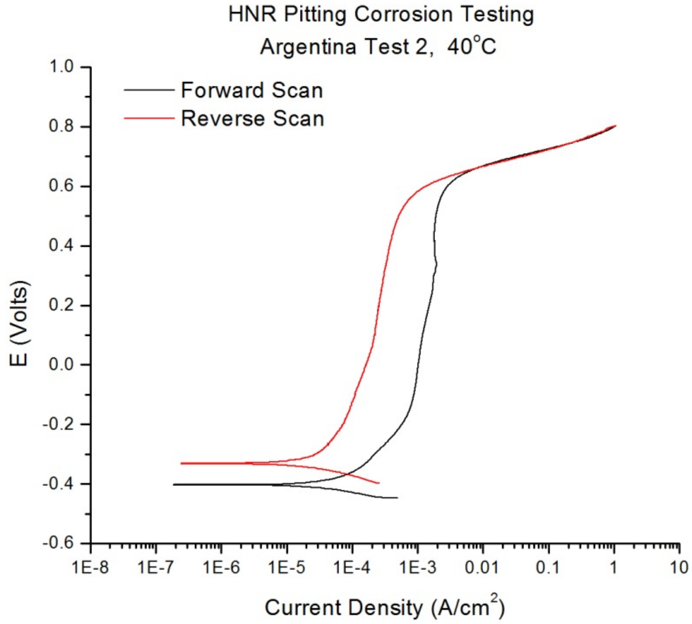
Comments/Notes:

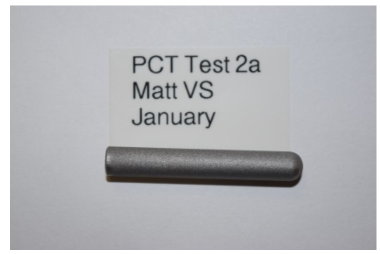
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	2a/b	2/02/16

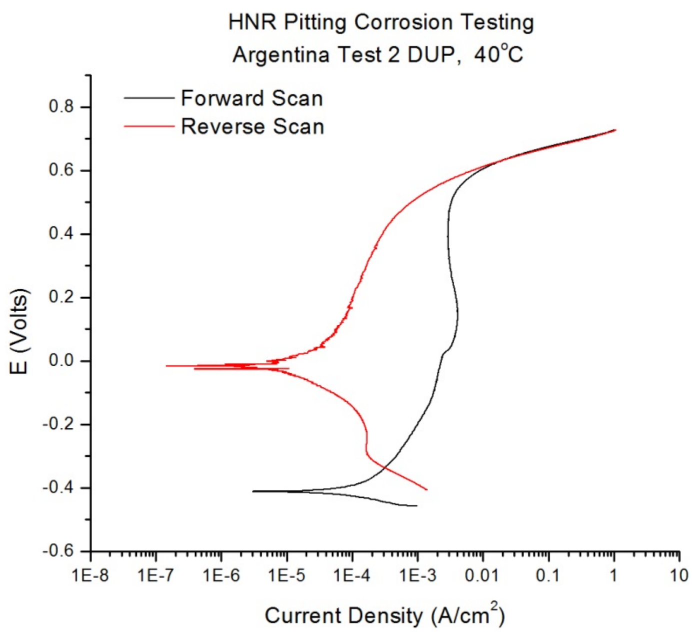
Prepared by: Matt Van Swol Date: 2/2/16 Reviewer: R. Wyrwas

Date Printed(2/1/2016

Cyclic Potentiodynamic Polarization Test 2







SRNL

Pitting Corrosion Testing, Task 3

Test ID **3**

This formula will make **1.4** Liters

Date: 2/2/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	1.1757	1.1753
3	Sodium Chloride	4.9090	4.8994
4	Sodium Nitrite	1.9319	1.94371
5	Sodium Sulfate	19.8982	19.9049
6	Sodium Phosphate, Tribasic 12	0.2661	0.2679
7	Sodium Carbonate	2.9677	2.9771
8	Sodium Citrate	14.6222	14.6233
9	Sodium Chromate	22.6842	22.6913
10	Sodium Nitrate	11.8993	11.8931

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.0800

Record pH: 11.05 Temp: °C

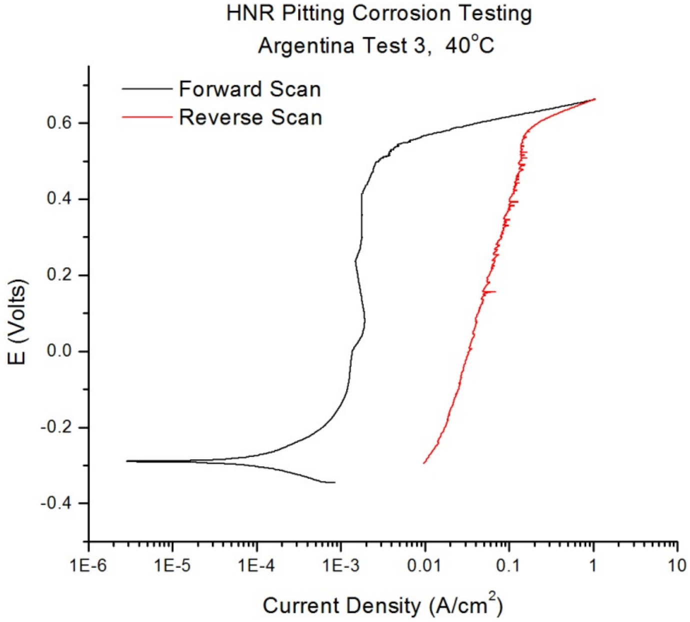
Comments/Notes:

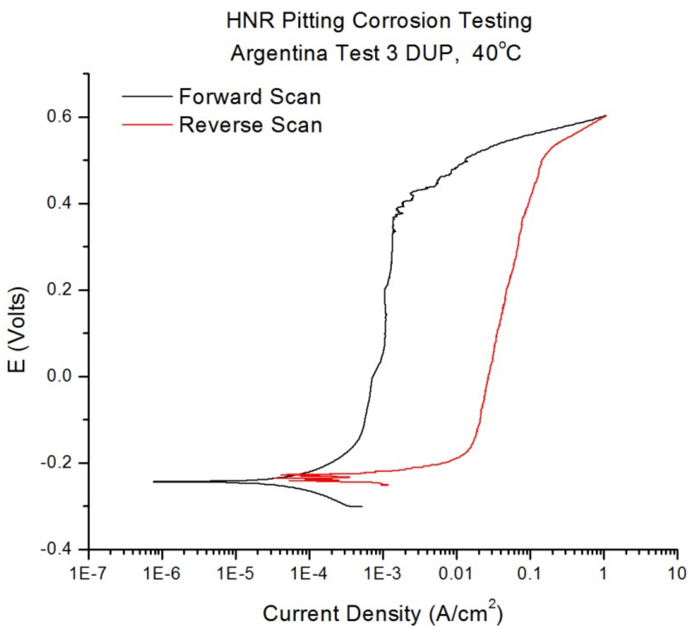
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	3a1b	2/2/16

Prepared by: Matt Van Swol Date: 2/2/16 Reviewer: A. Wyrwas

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 3





SRNL

Pitting Corrosion Testing, Task 3

Test ID **4**

This formula will make **1.4** Liters

Date: 2/2/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	0.1764	0.1753
3	Sodium Chloride	32.7264	32.7341
4	Sodium Nitrite	1.9319	1.9329
5	Sodium Sulfate	0.9949	0.9895
6	Sodium Phosphate, Tribasic 12	0.2661	0.2917
7	Sodium Carbonate	2.9677	2.9688
8	Sodium Citrate	14.6222	14.6133
9	Sodium Chromate	22.6842	22.6907
10	Sodium Nitrate	11.8993	11.8901

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 10.8400

Record pH: 11.10 Temp: °C

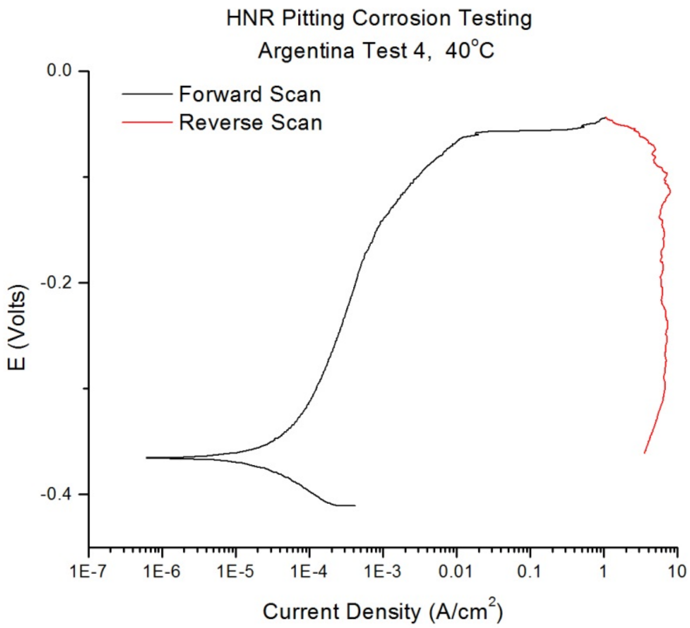
Comments/Notes:

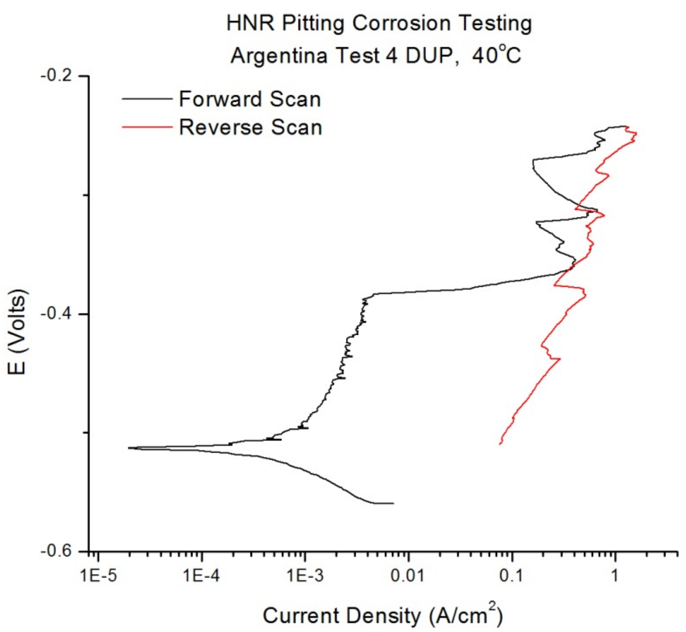
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
FD2232	4a/b	2/2/16

Prepared by: Matt Van Swol Date: 2/2/16 Reviewer: R. Wyrwas

Date Printed(2/1/2016

Cyclic Potentiodynamic Polarization Test 4





SRNL

Pitting Corrosion Testing, Task 3

Test ID 5

This formula will make **1.4** Liters

Date: 2/2/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	0.1764	0.1739
3	Sodium Chloride	32.7264	32.6901
4	Sodium Nitrite	48.2965	48.3109
5	Sodium Sulfate	19.8982	19.8370
6	Sodium Phosphate, Tribasic 12	26.6084	26.6053
7	Sodium Carbonate	29.6772	29.6811
8	Sodium Citrate	219.3324	219.4132
9	Sodium Chromate	0.0227	0.0231
10	Sodium Nitrate	11.8993	11.8733

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.3000

Record pH: 10.84 Temp: °C

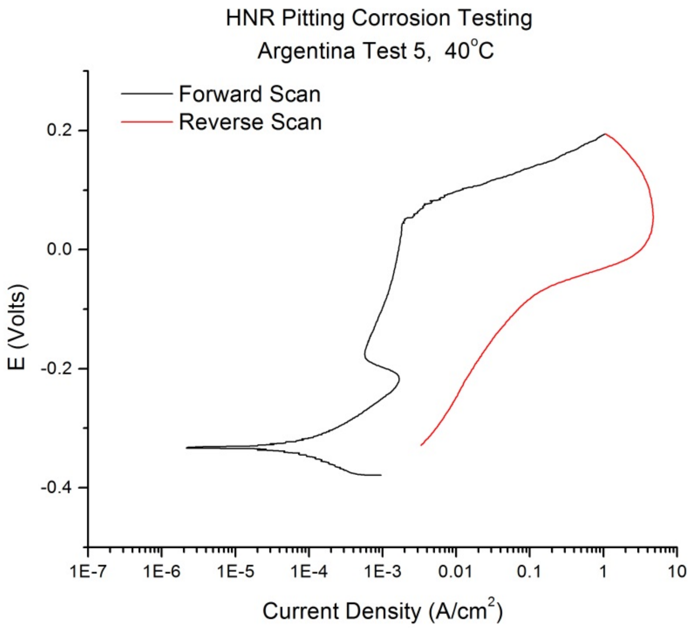
Comments/Notes: large bubbles formed when citrate was added

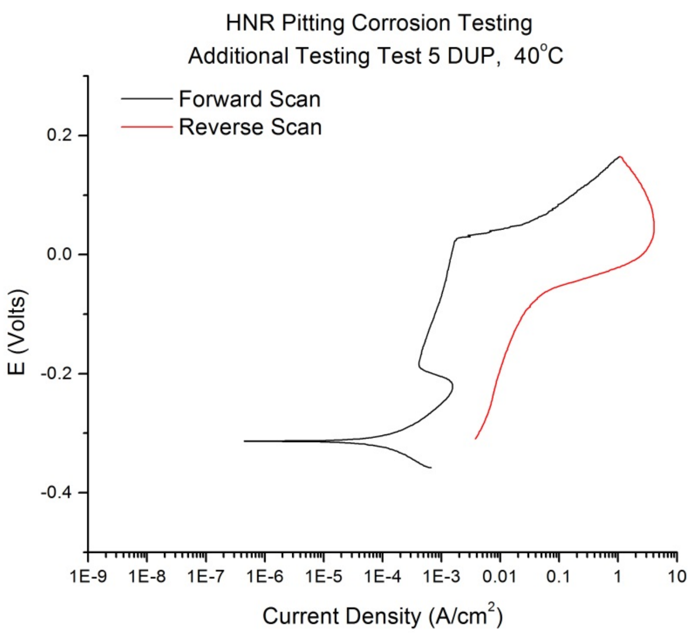
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
I02232	5a16	2/2/16

Prepared by: Matt Van Swol Date: 2/2/16 Reviewer: R. Wyrwas

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 5





SRNL

Pitting Corrosion Testing, Task 3

Test ID **6**

This formula will make **1.4** Liters

Date: 2/3/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.0000	0
2	Sodium Fluoride	2.9392	2.9401
3	Sodium Chloride	32.7264	32.7314
4	Sodium Nitrite	9.6593	9.6632
5	Sodium Sulfate	19.8982	19.8864
6	Sodium Phosphate, Tribasic 12	0.2661	0.2253
7	Sodium Carbonate	2.9677	2.9668
8	Sodium Citrate	219.3324	219.3291
9	Sodium Chromate	22.6842	22.6835
10	Sodium Nitrate	11.8993	11.8975

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 10.7700

Record pH: 10.74 Temp: °C

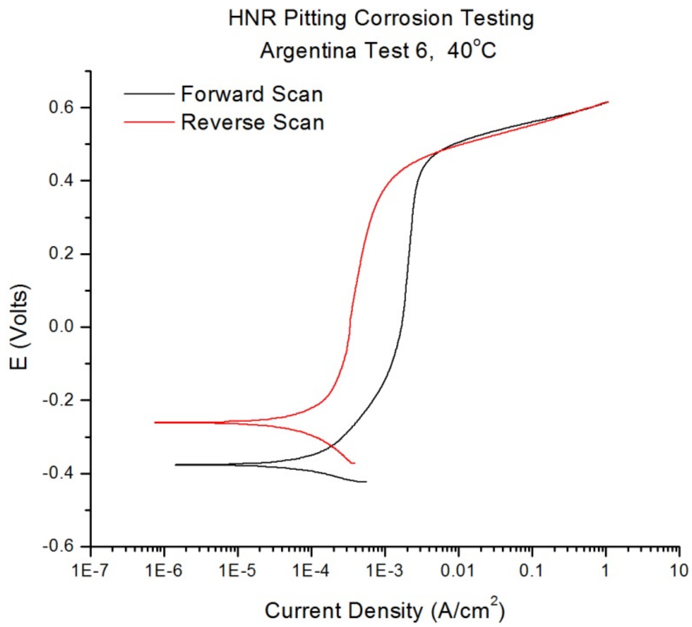
Comments/Notes: Addition of citrate caused solution to fizz.

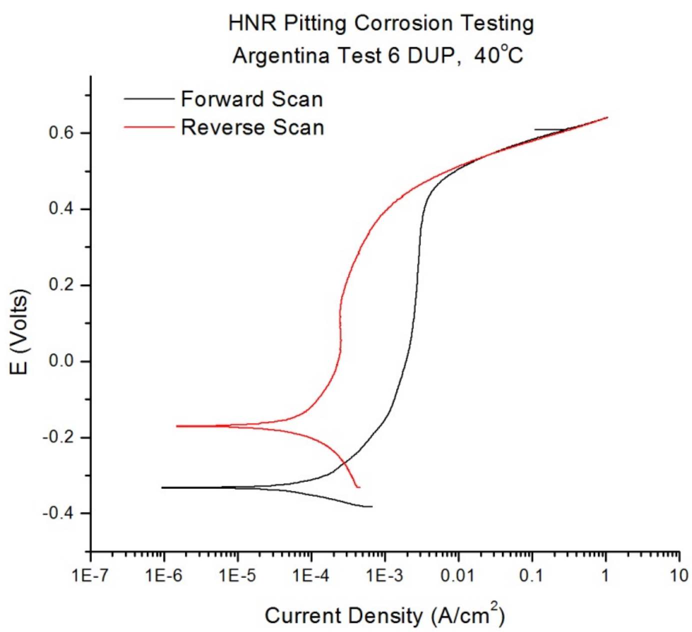
CPP Testing	**Test Temperature:** 40°C	
Coupon ID	File name	Date
I2232	6a16	2/3/16

Prepared by: Matt Van Swol Date: 2/3/16 Reviewer: R. Wyrwas

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 6





SRNL

Pitting Corrosion Testing, Task 3

Test ID **7**

This formula will make **1.4** Liters

Date: 2/11/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0
2	Sodium Fluoride	0.1764	0.1752
3	Sodium Chloride	4.9090	4.9123
4	Sodium Nitrite	9.6593	9.6583
5	Sodium Sulfate	19.8982	19.8988
6	Sodium Phosphate, Tribasic 12	26.6084	26.6132
7	Sodium Carbonate	2.9677	2.9664
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6219
9	Sodium Chromate	22.6842	22.6834
10	Sodium Nitrate	11.8993	11.8973

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.8700

Record pH: 11.86 Temp: °C

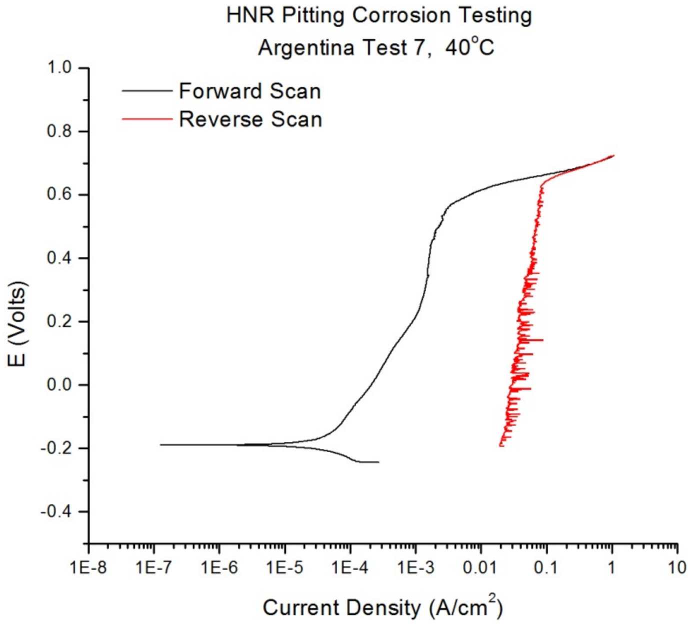
Comments/Notes:

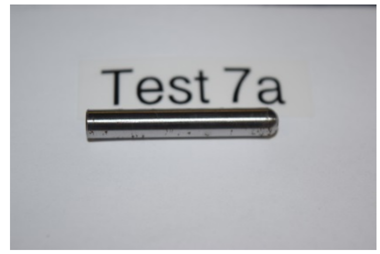
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
I02232	Test 7a/b	2/11/16

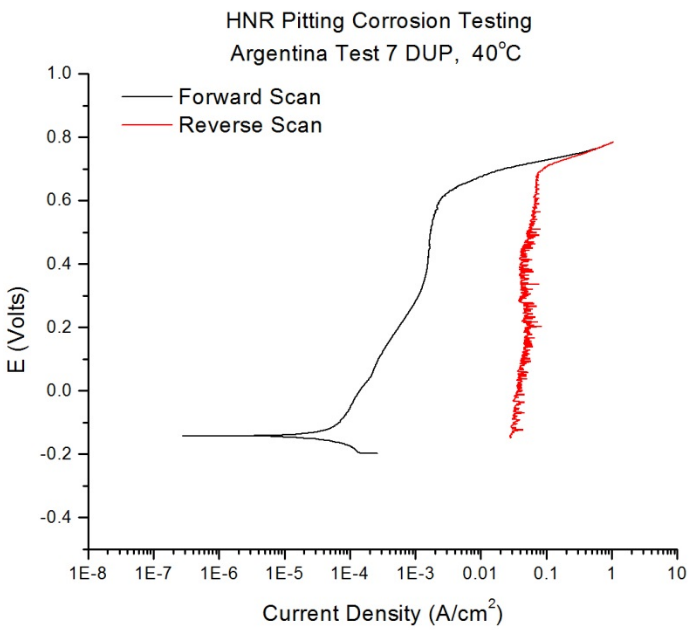
Prepared by: Matt VS Date: 2/11/16 Reviewer: [signature]

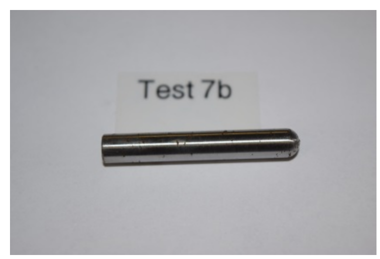
Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 7









SRNL

Pitting Corrosion Testing, Task 3

Test ID **8**

This formula will make **1.4** Liters

Date: 2/6/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5659
2	Sodium Fluoride	2.9392	2.9361
3	Sodium Chloride	4.9090	4.9069
4	Sodium Nitrite	9.6593	9.6562
5	Sodium Sulfate	0.9949	0.9936
6	Sodium Phosphate, Tribasic 12	26.6084	26.6071
7	Sodium Carbonate	29.6772	29.6708
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6198
9	Sodium Chromate	1.1342	1.1335
10	Sodium Nitrate	83.2951	83.2959

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.9

Record pH: 11.90 Temp: °C

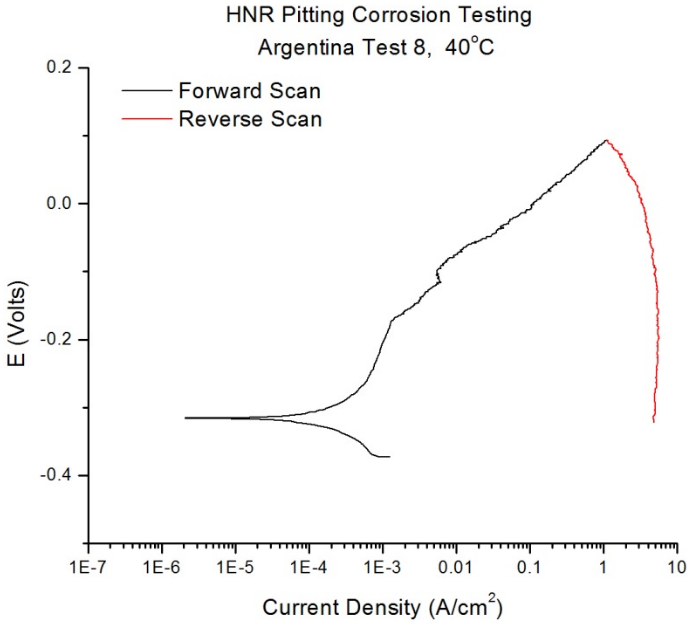
Comments/Notes:

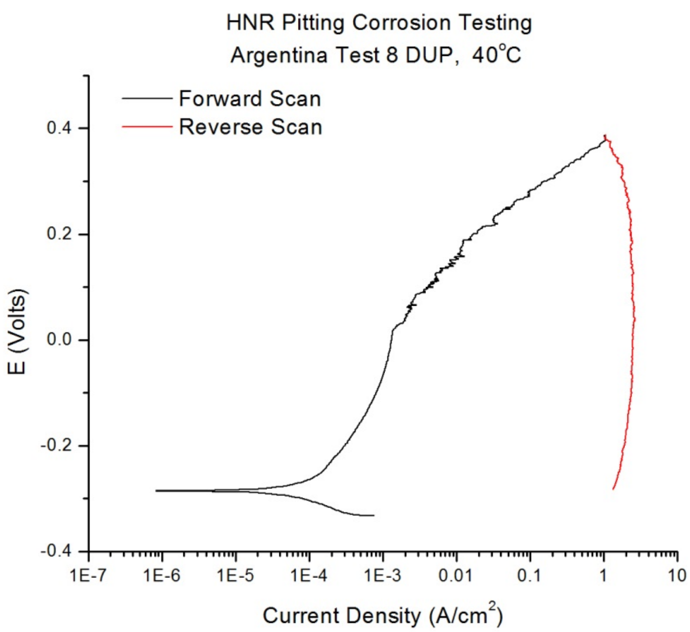
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	Test 8a16	2/16/16

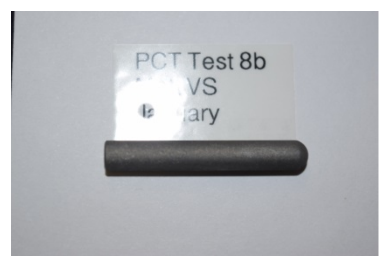
Prepared by: Matt B. Date: 2/16/16 Reviewer: [signature]

Date Printed 2/16/2016

Cyclic Potentiodynamic Polarization Test 8







SRNL

Pitting Corrosion Testing, Task 3

Test ID **9**

This formula will make **1.4** Liters

Date: 2/08/16 Batch no.: 4

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5632
2	Sodium Fluoride	2.9392	2.9395
3	Sodium Chloride	4.9090	4.9013
4	Sodium Nitrite	1.9319	1.9325
5	Sodium Sulfate	19.8982	19.8923
6	Sodium Phosphate, Tribasic 12	26.6084	26.6039
7	Sodium Carbonate	29.6772	29.6779
8	Sodium Citrate	14.6222	14.6261
9	Sodium Chromate	22.6842	22.6839
10	Sodium Nitrate	83.2951	83.3167

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 11.7000

Record pH: 11.72 Temp: °C

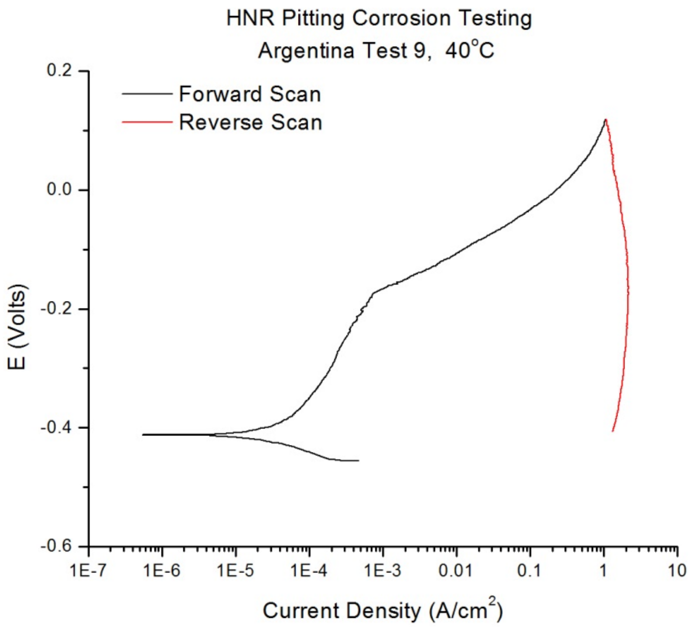
Comments/Notes:

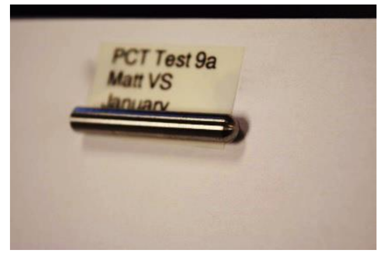
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2282	Test 9a/b	2/08/16

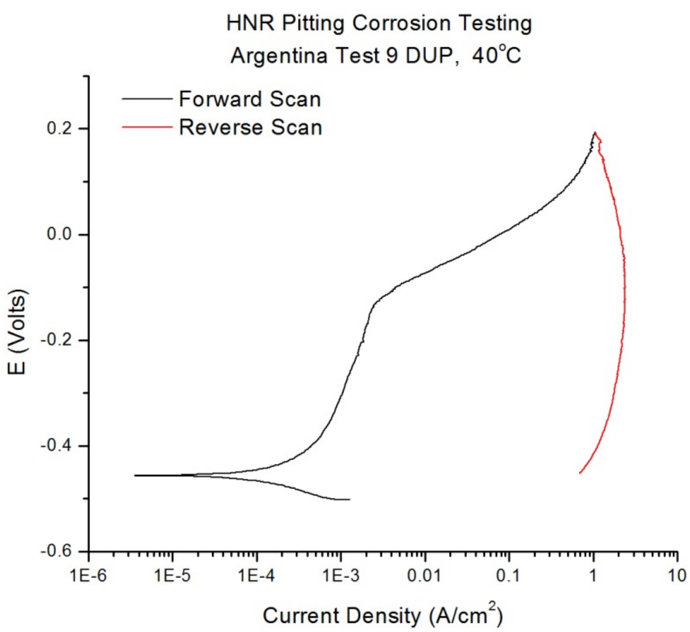
Prepared by: [signature] Date: 2/08/16 Reviewer: [signature]

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 9







SRNL

Pitting Corrosion Testing, Task 3

Test ID **10**

This formula will make **1.4** Liters

Date: 2/16/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5598
2	Sodium Fluoride	1.1757	1.1762
3	Sodium Chloride	32.7264	32.7254
4	Sodium Nitrite	48.2965	48.2937
5	Sodium Sulfate	0.9949	0.9932
6	Sodium Phosphate, Tribasic 12	0.2661	0.2674
7	Sodium Carbonate	2.9677	2.9604
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6213
9	Sodium Chromate	1.1342	1.1366
10	Sodium Nitrate	11.8993	11.8974

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.1

Record pH: 12.10 Temp: °C

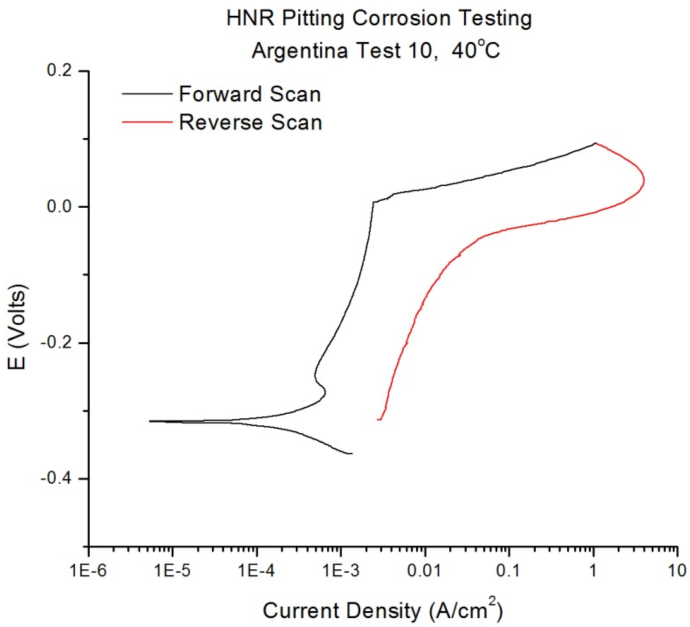
Comments/Notes: ______

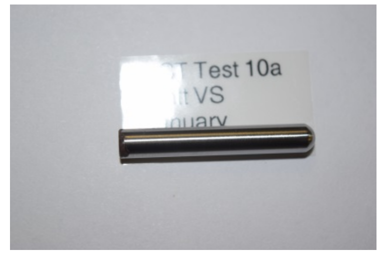
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	T3ra 10a 1b	2/16/16

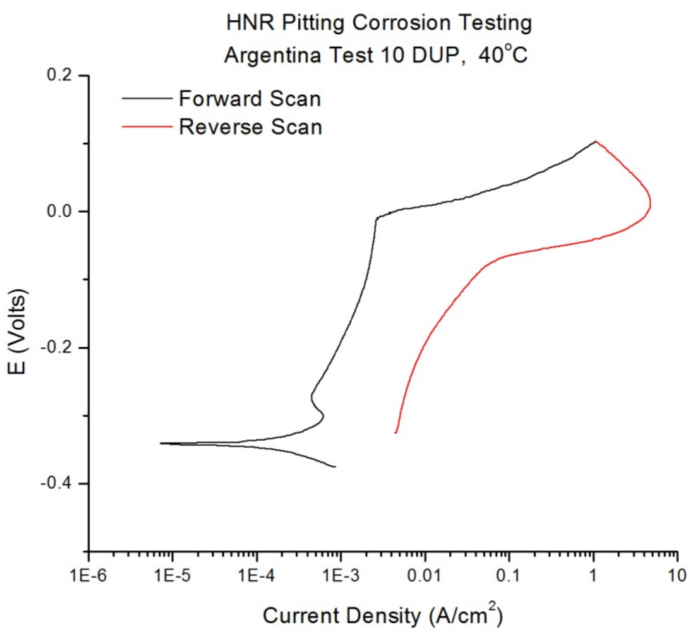
Prepared by: Helen VS. Date: 2/16/16 Reviewer: [signature]

Date Printed 2/16/2016

Cyclic Potentiodynamic Polarization Test 10







SRNL

Pitting Corrosion Testing, Task 3

Test ID **11**

This formula will make **1.4** Liters

Date: 2/08/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5661
2	Sodium Fluoride	0.1764	0.1734
3	Sodium Chloride	0.8182	0.8189
4	Sodium Nitrite	9.6593	9.6534
5	Sodium Sulfate	0.9949	0.9839
6	Sodium Phosphate, Tribasic 12	0.2661	0.2713
7	Sodium Carbonate	2.9677	2.9674
8	Sodium Citrate	14.6222	14.7391
9	Sodium Chromate	1.1342	1.1295
10	Sodium Nitrate	83.2951	83.4891

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.1500

Record pH: 13.17 Temp: °C

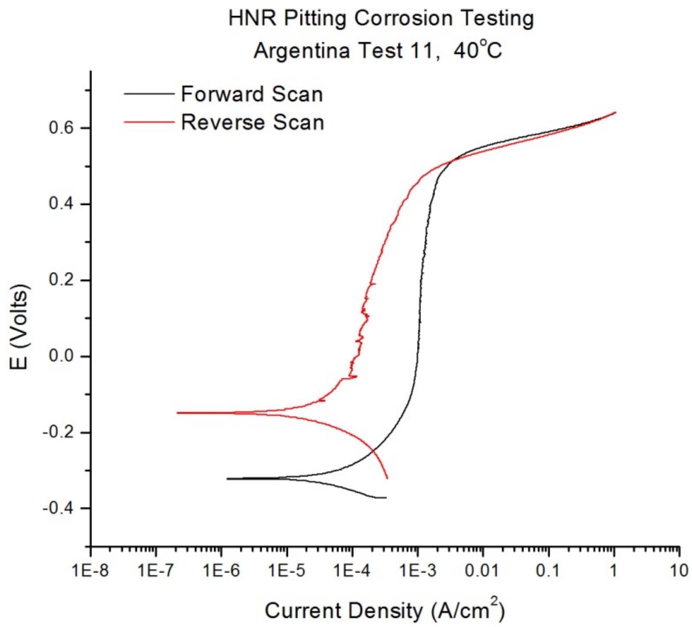
Comments/Notes:

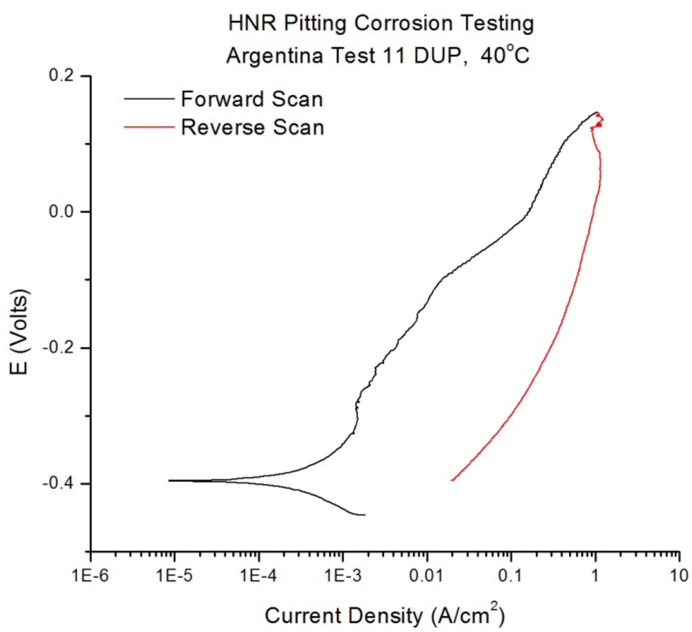
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	Test 11a/6	2/08/16

Prepared by: Matt V[signature] Date: 2/08/16 Reviewer: [signature]

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 11





SRNL

Pitting Corrosion Testing, Task 3

Test ID **12**

This formula will make **1.4** Liters

Date: 2/08/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.6135
2	Sodium Fluoride	2.9392	2.9325
3	Sodium Chloride	0.8182	0.8185
4	Sodium Nitrite	1.9319	1.9337
5	Sodium Sulfate	0.9949	0.9952
6	Sodium Phosphate, Tribasic 12	26.6084	26.6158
7	Sodium Carbonate	2.9677	2.9673
8	Sodium Citrate	14.6222	14.6153
9	Sodium Chromate	1.1342	1.1327
10	Sodium Nitrate	11.8993	11.8971

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.0600

Record pH: 13.05 Temp: °C

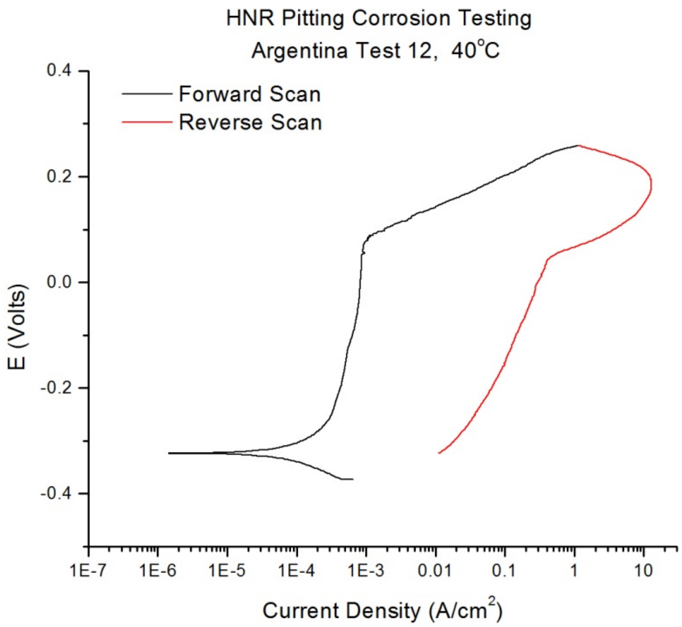
Comments/Notes:

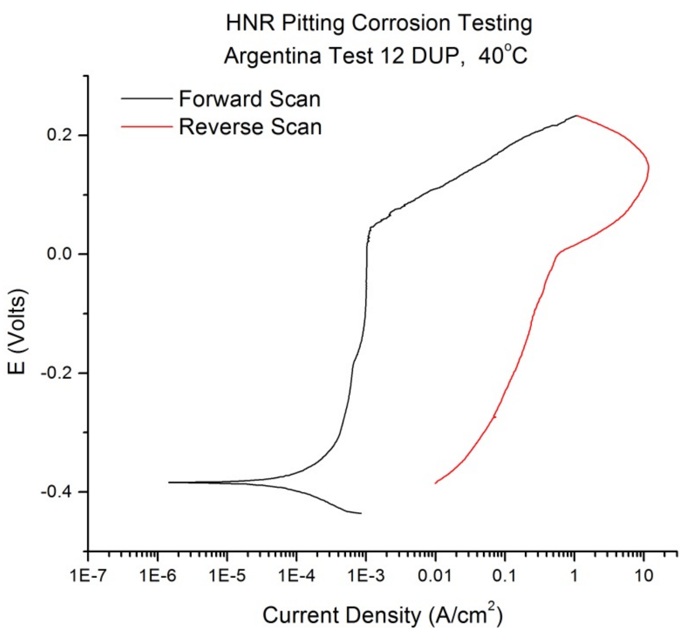
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
I02232	Test 12a/b	2/08/16

Prepared by: [signature] Date: 2/08/16 Reviewer: [signature]

Date Printed(2/2/2016

Cyclic Potentiodynamic Polarization Test 12





SRNL

Pitting Corrosion Testing, Task 3

Test ID **13**

This formula will make **1.4** Liters

Date: 2/16/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.6085
2	Sodium Fluoride	1.1757	1.1746
3	Sodium Chloride	0.8182	0.8118
4	Sodium Nitrite	48.2965	48.2942
5	Sodium Sulfate	19.8982	19.8919
6	Sodium Phosphate, Tribasic 12	0.2661	0.2680
7	Sodium Carbonate	2.9677	2.9626
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6237
9	Sodium Chromate	1.1342	1.1323
10	Sodium Nitrate	11.8993	11.8973

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.0

Record pH: 13.03 Temp: °C

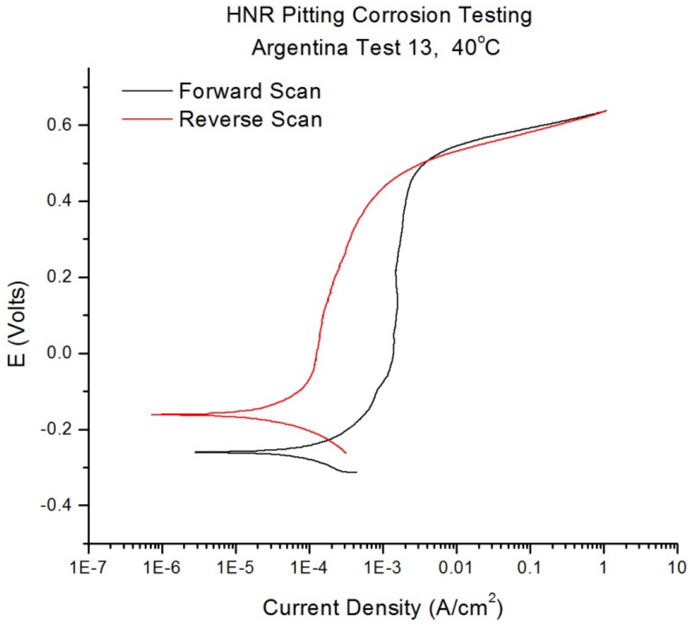
Comments/Notes:

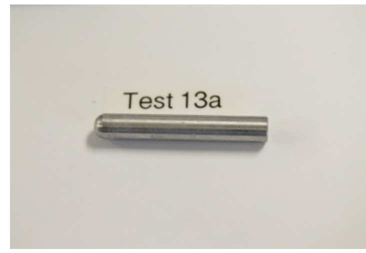
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ED2232	~~[illegible]~~ Test 13a/b	2/16/16

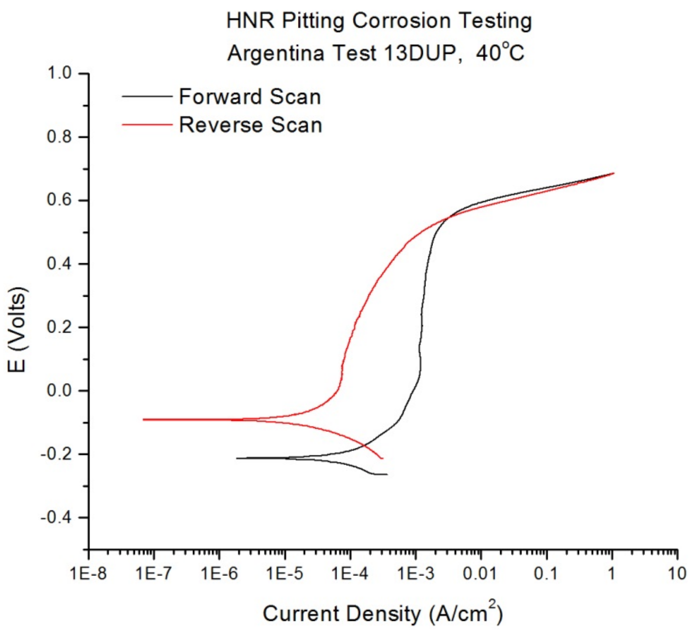
Prepared by: Mark VS Date: 2/16/16 Reviewer: [signature]

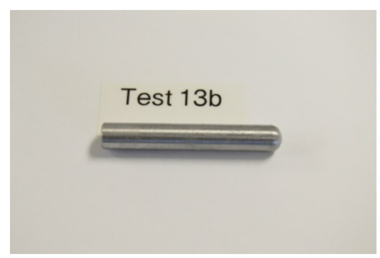
Date Printed 2/16/2016

Cyclic Potentiodynamic Polarization Test 13









SRNL

Pitting Corrosion Testing, Task 3

Test ID **14**

This formula will make **1.4** Liters

Date: 2/16/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.5937
2	Sodium Fluoride	2.9392	2.9366
3	Sodium Chloride	4.9090	4.9072
4	Sodium Nitrite	9.6593	9.6594
5	Sodium Sulfate	0.9949	0.9951
6	Sodium Phosphate, Tribasic 12	26.6084	26.6001
7	Sodium Carbonate	29.6772	29.6718
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6281
9	Sodium Chromate	1.1342	1.1363
10	Sodium Nitrate	11.8993	11.8997

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.2

Record pH: 13.18 Temp: °C

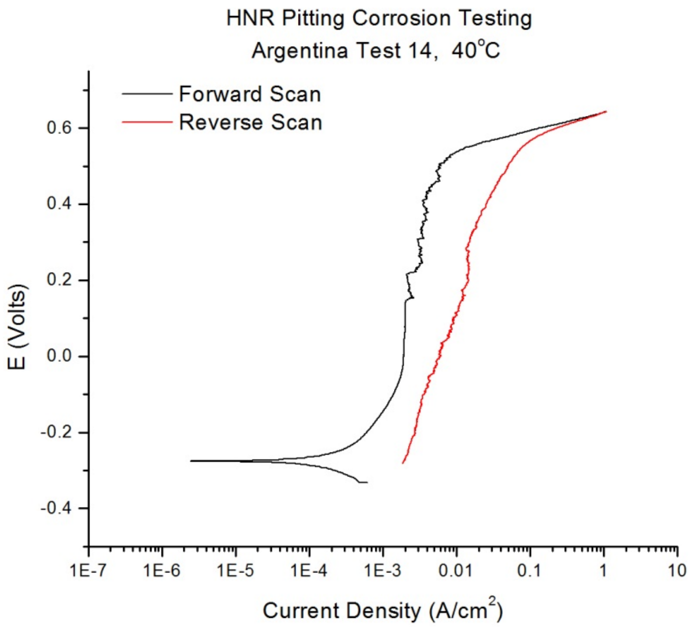
Comments/Notes: 10mL wt = 10.4386g

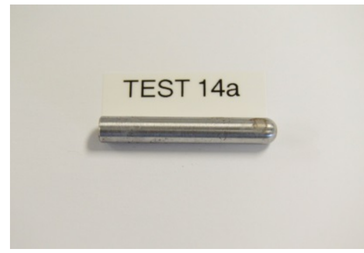
CPP Testing	**Test Temperature:**	
Coupon ID	File name	Date
ID2232	Test 14a/b	2/16/16

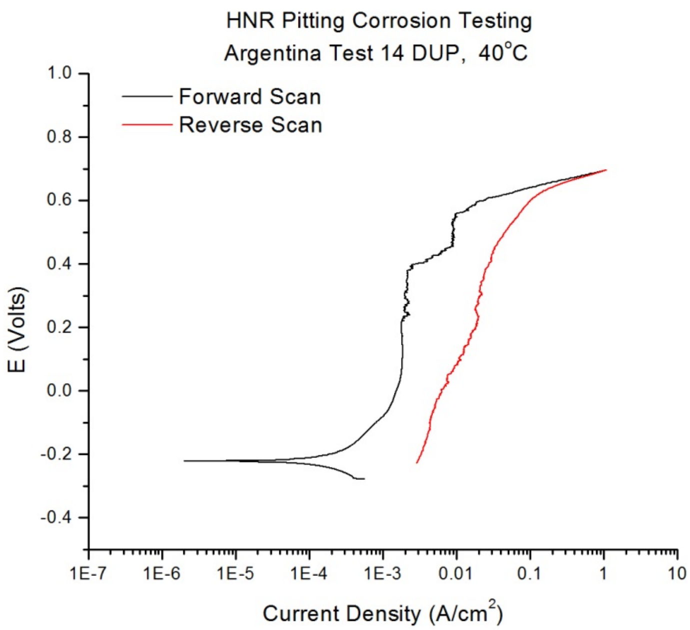
Prepared by: Mary VS. Date: 2/16/16 Reviewer: [signature]

Date Printed 2/16/2016

Cyclic Potentiodynamic Polarization Test 14







SRNL

Pitting Corrosion Testing, Task 3

Test ID **15**

This formula will make **1.4** Liters

Date: 2/08/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.6084
2	Sodium Fluoride	0.1764	0.1762
3	Sodium Chloride	32.7264	32.7271
4	Sodium Nitrite	1.9319	1.9323
5	Sodium Sulfate	19.8982	19.8985
6	Sodium Phosphate, Tribasic 12	0.2661	0.2665
7	Sodium Carbonate	29.6772	29.6779
8	Sodium Citrate	14.6222	14.6230
9	Sodium Chromate	1.1342	1.1341
10	Sodium Nitrate	11.8993	11.8995

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.1660

Record pH: ______ Temp: °C

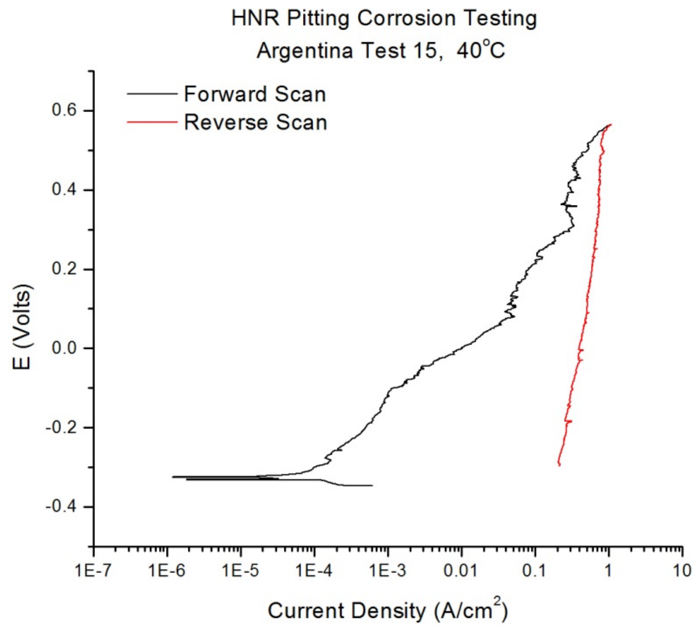
Comments/Notes: Liquid Wt @ 10mL = 10.4848g

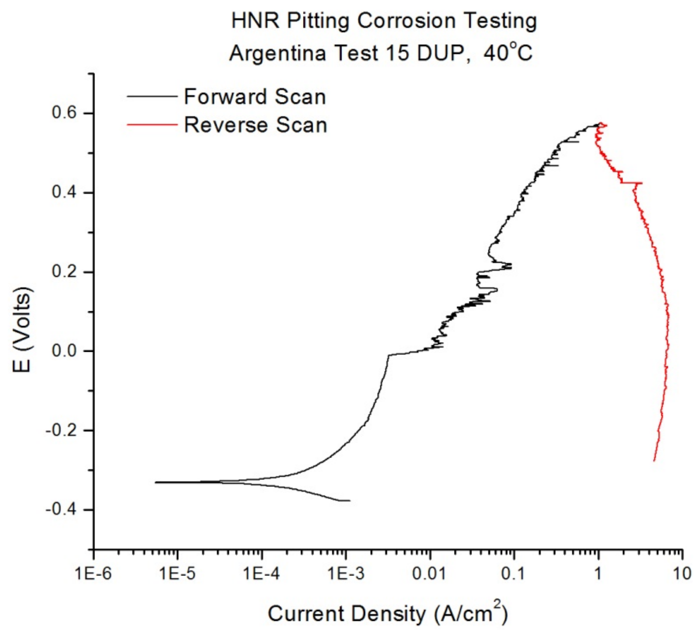
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 15a/b	2/08/16

Prepared by: Kellie Hair Date: 2/08/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 15





SRNL

Pitting Corrosion Testing, Task 3

Test ID **16**

This formula will make **1.4** Liters

Date: 2/16/16 Batch no.: 4

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.6111
2	Sodium Fluoride	0.1764	0.1770
3	Sodium Chloride	32.7264	32.7249
4	Sodium Nitrite	48.2965	48.2932
5	Sodium Sulfate	0.9949	0.9962
6	Sodium Phosphate, Tribasic 12	0.2661	0.2668
7	Sodium Carbonate	2.9677	2.9605
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6282
9	Sodium Chromate	22.6842	22.6831
10	Sodium Nitrate	11.8993	11.8983

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.9800

Record pH: 12.97 Temp: °C

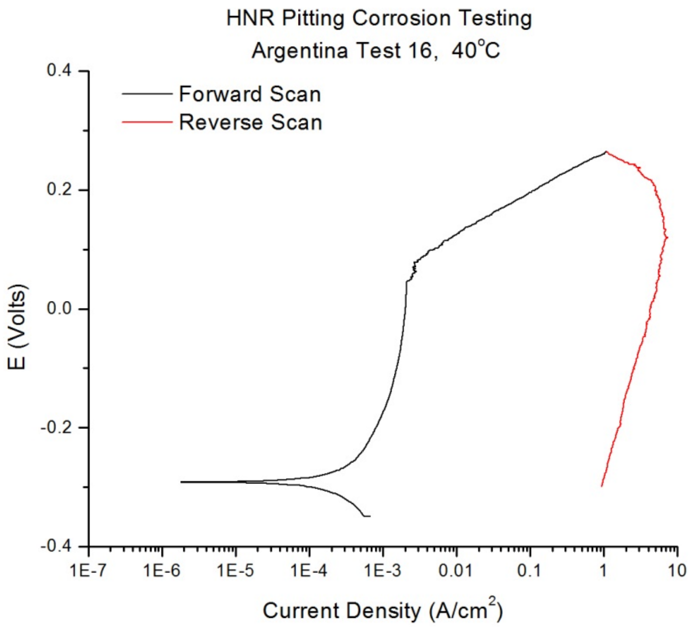
Comments/Notes:

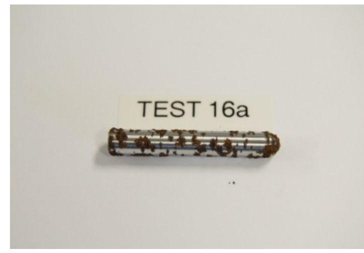
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
I02232	Test 16a	2/16/16

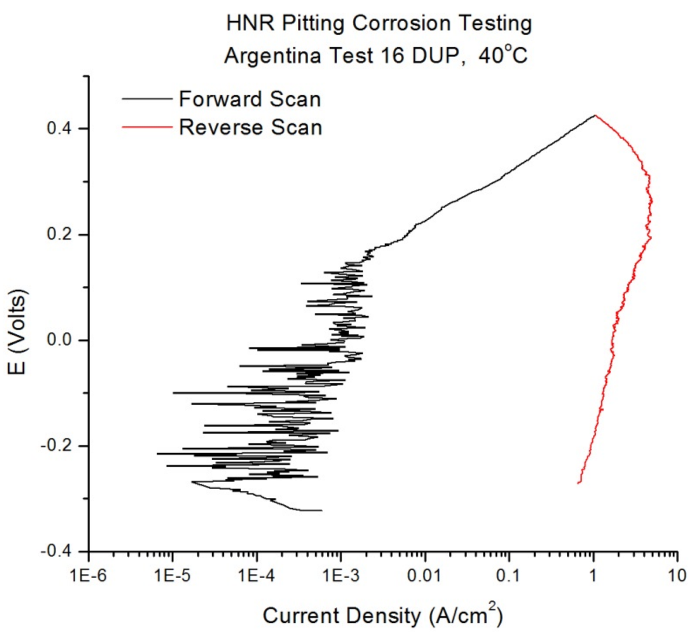
Prepared by: Mike VS. Date: 2/16/16 Reviewer: R. W

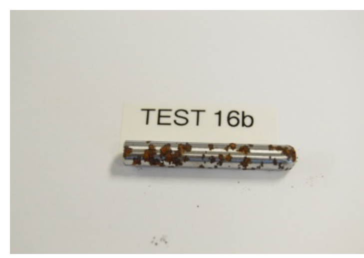
Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 16









Pitting Corrosion Testing, Task 3

Test ID **17**

This formula will make **1.4** Liters

Date: 2/4/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.5608
2	Sodium Fluoride	1.1757	1.1733
3	Sodium Chloride	32.7264	32.7343
4	Sodium Nitrite	1.9319	1.9291
5	Sodium Sulfate	19.8982	19.9342
6	Sodium Phosphate, Tribasic 1:	26.6084	26.6132
7	Sodium Carbonate	2.9677	2.9720
8	Sodium Citrate	14.6222	14.6277
9	Sodium Chromate	1.1342	~~[illegible]~~ 1.1418
10	Sodium Nitrate	11.8993	11.8991

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.9200

Record pH: 12.91 Temp: °C

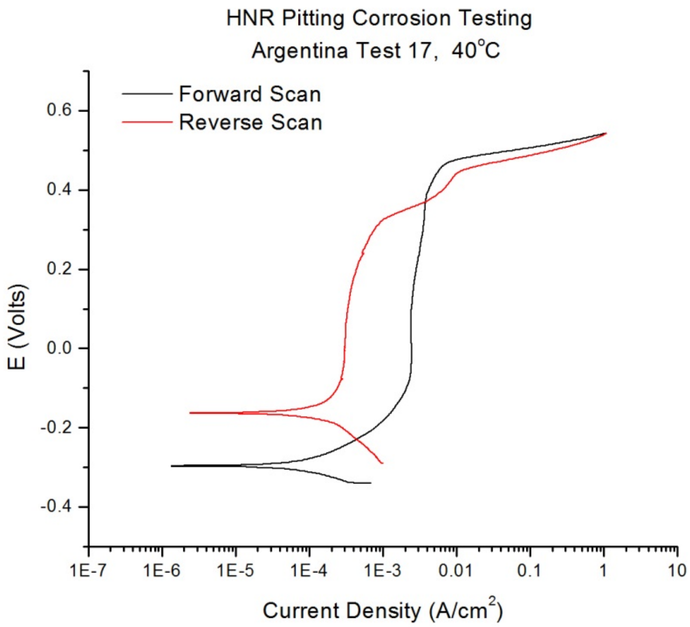
Comments/Notes:

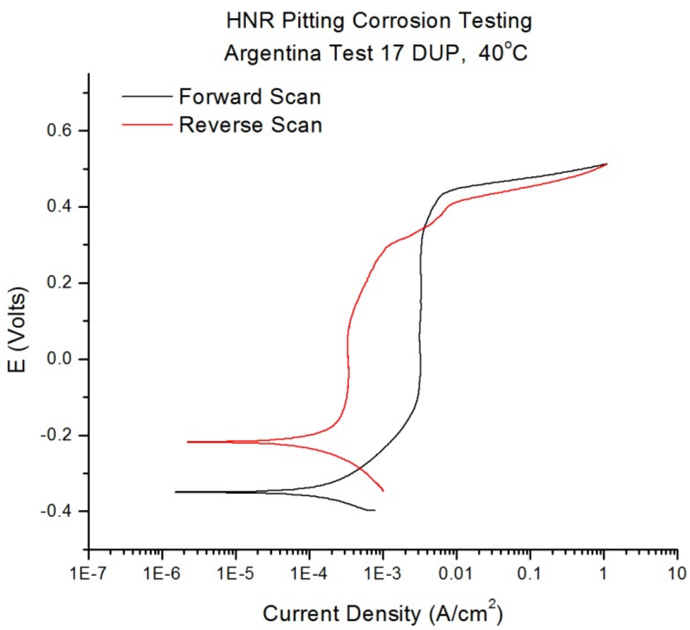
CPP Testing	Test Temperature: 40°C	
Coupon ID	File name	Date
ID2232	17a/b	2/4/16

Prepared by: Matt Van Swol Date: 2/4/16 Reviewer: R. W.

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 17





SRNL

Pitting Corrosion Testing, Task 3

Test ID **18**

This formula will make **1.4** Liters

Date: 2/16/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	5.6000	5.6113
2	Sodium Fluoride	1.1757	1.1743
3	Sodium Chloride	32.7264	32.7262
4	Sodium Nitrite	48.2965	48.2971
5	Sodium Sulfate	19.8982	19.8987
6	Sodium Phosphate, Tribasic 12	26.6084	26.6093
7	Sodium Carbonate	29.6772	29.6719
8	Sodium Citrate	14.6222 ~~219.3324~~	14.6234
9	Sodium Chromate	22.6842	22.6831
10	Sodium Nitrate	83.2951	83.2991

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 13.0300

Record pH: 13.02 Temp: °C

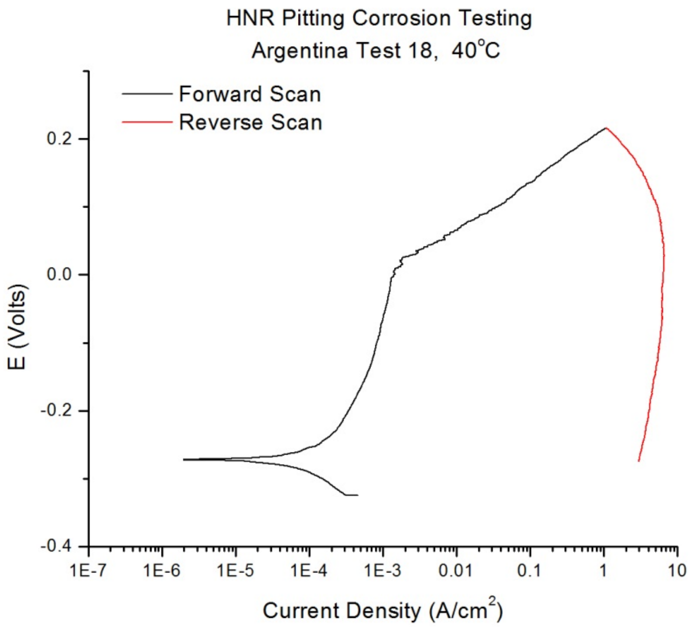
Comments/Notes:

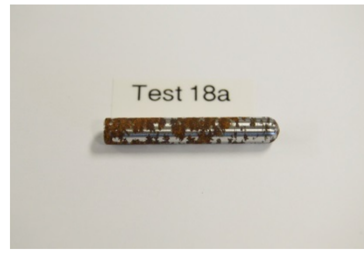
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 18a/b	2/16/16

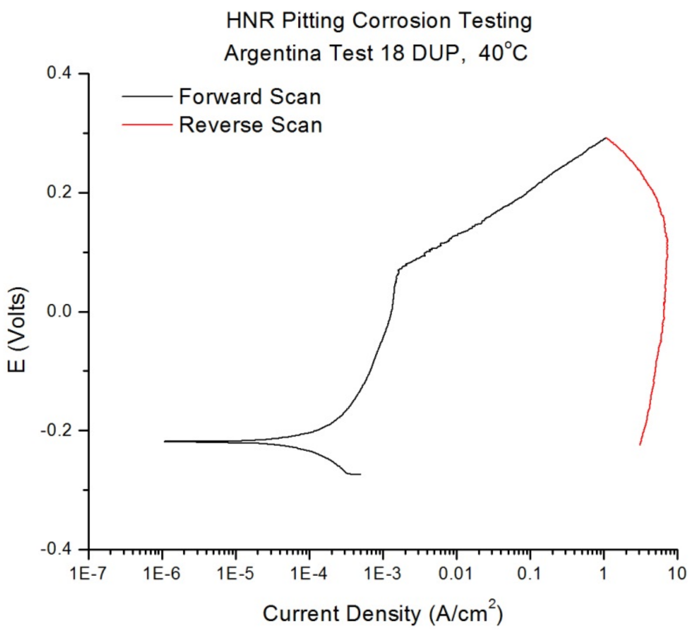
Prepared by: Mary VS. Date: 2/16/16 Reviewer: R. Wa

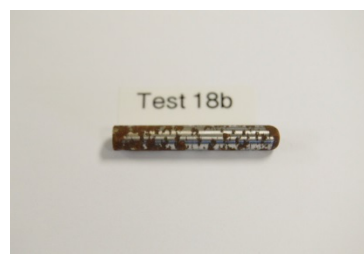
Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 18









SRNL

Pitting Corrosion Testing, Task 3

Test ID **19**

This formula will make **1.4** Liters

Date: 2/4/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5593
2	Sodium Fluoride	0.1764	0.1872
3	Sodium Chloride	4.9090	4.9113
4	Sodium Nitrite	9.6593	9.6582
5	Sodium Sulfate	0.9949	0.9925
6	Sodium Phosphate, Tribasic 12	5.3217	5.3261
7	Sodium Carbonate	2.9677	2.9671
8	Sodium Citrate	14.6222	14.6225
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	59.4965	59.4936

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.99 Temp: °C

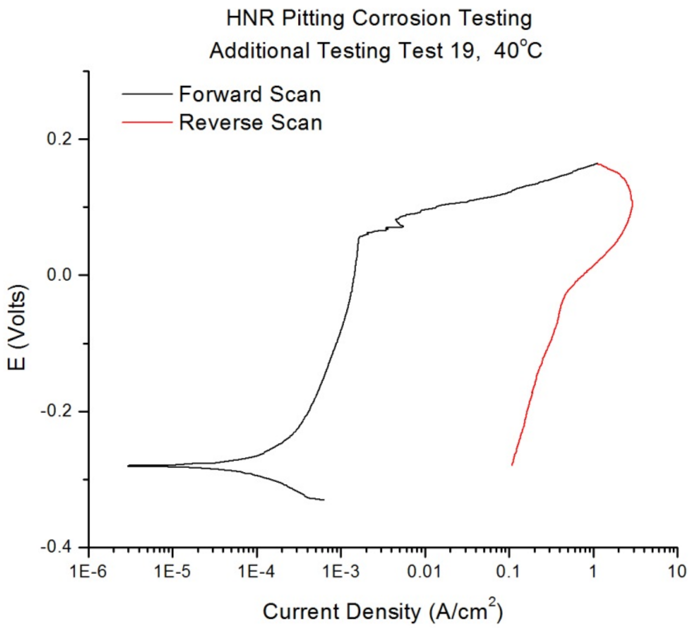
Comments/Notes:

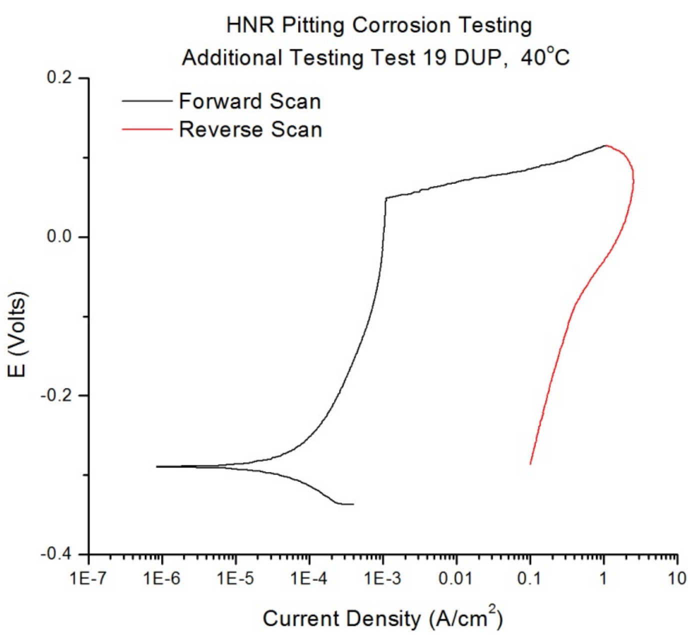
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	19a1h	2/4/16

Prepared by: Matt V.S. Date: 2/4/16 Reviewer: [signature]

Date Printed 2/3/2016

Cyclic Potentiodynamic Polarization Test 19





SRNL

Pitting Corrosion Testing, Task 3

Test ID **20**

This formula will make **1.4** Liters

Date: 2/4/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5662
2	Sodium Fluoride	0.5878	0.5931
3	Sodium Chloride	4.9090	4.9110
4	Sodium Nitrite	48.2965	48.2952
5	Sodium Sulfate	19.8982	19.8977
6	Sodium Phosphate, Tribasic 12	2.6608	2.6713
7	Sodium Carbonate	29.6772	29.6764
8	Sodium Citrate	14.6222	14.6319
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	59.4965	59.5031

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.97 Temp: °C

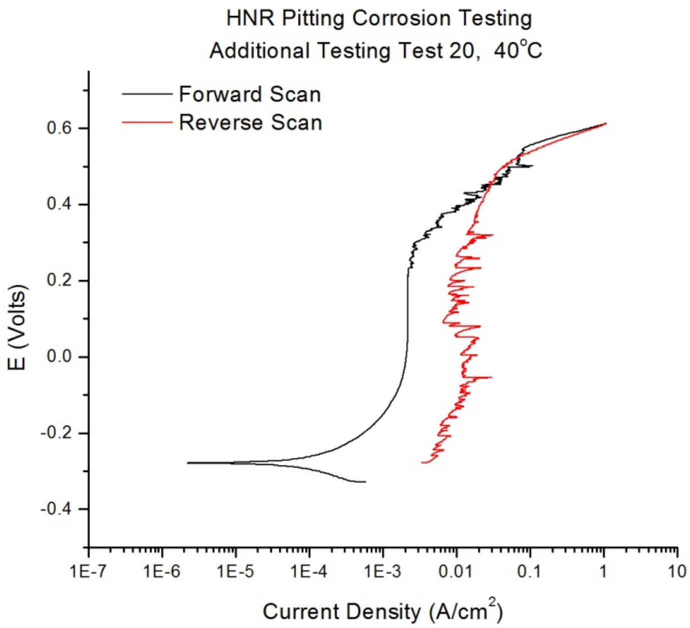
Comments/Notes:

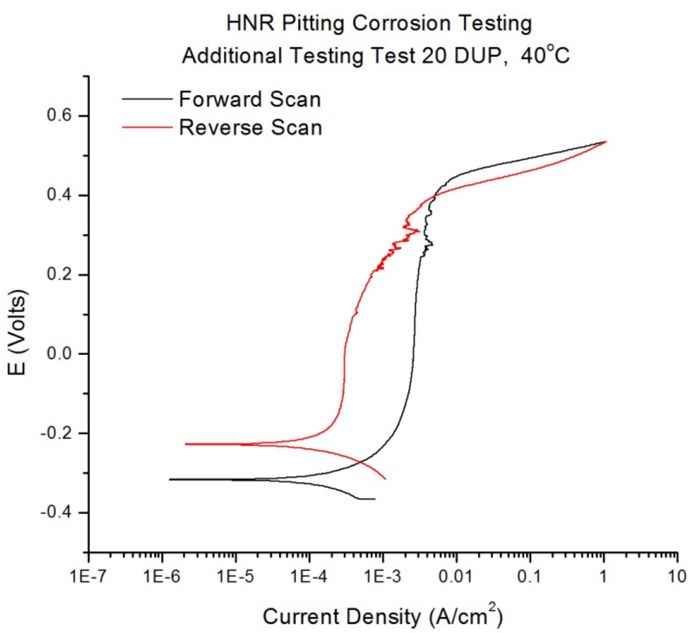
CPP Testing	Test Temperature: 40°C	
Coupon ID	File name	Date
I02232	20a/b	2/4/16

Prepared by: Mats VanSool Date: 2/4/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 20





SRNL

Pitting Corrosion Testing, Task 3

Test ID **21**

This formula will make **1.4** Liters

Date: 2/09/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5613
2	Sodium Fluoride	0.1764	0.1739
3	Sodium Chloride	32.7264	32.7199
4	Sodium Nitrite	96.5930	96.5922
5	Sodium Sulfate	0.9949	0.9936
6	Sodium Phosphate, Tribasic 12	2.6608	2.6613
7	Sodium Carbonate	29.6772	29.6886
8	Sodium Citrate	14.6222	14.6319
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	59.4965	59.4371

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.98 Temp: °C

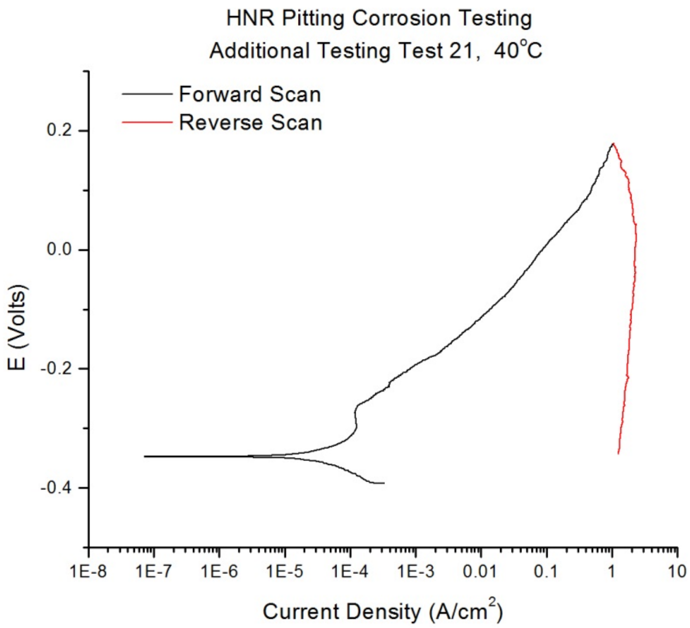
Comments/Notes:

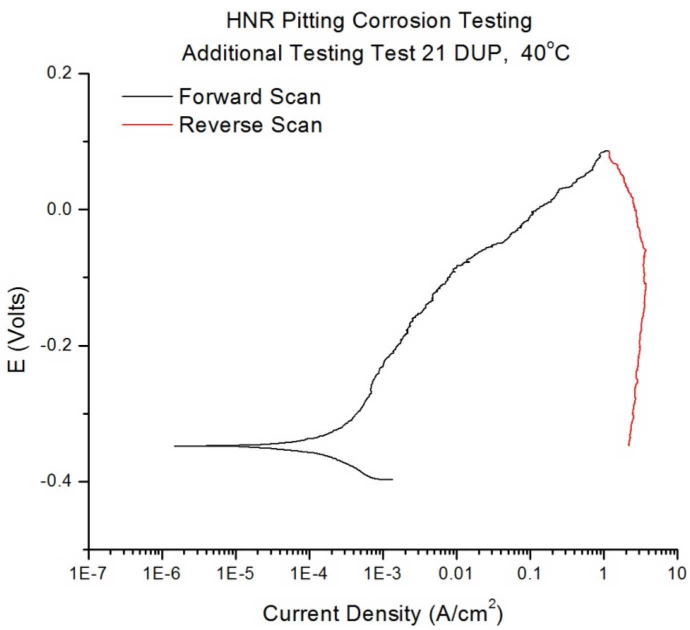
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 21a/b	2/09/16

Prepared by: Matt Van A Date: 2/09/16 Reviewer: R. Wee

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 21





SRNL

Pitting Corrosion Testing, Task 3

Test ID **22**

This formula will make **1.4** Liters

Date: 2/09/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5569
2	Sodium Fluoride	0.5878	0.5798
3	Sodium Chloride	4.9090	4.8905
4	Sodium Nitrite	48.2965	48.3051
5	Sodium Sulfate	0.9949	0.9881
6	Sodium Phosphate, Tribasic 1:	5.3217	5.3228
7	Sodium Carbonate	2.9677	2.9671
8	Sodium Citrate	14.6222	14.6273
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	118.9930	118.9933

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.99 Temp: °C

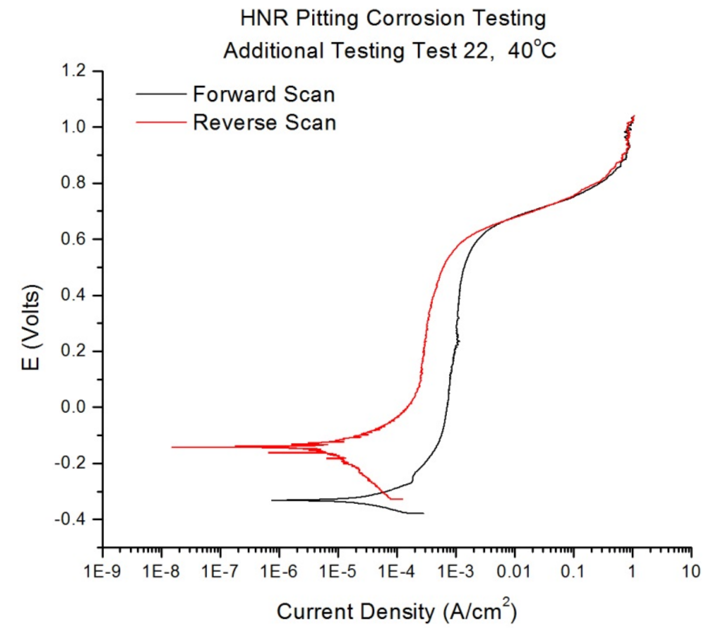
Comments/Notes:

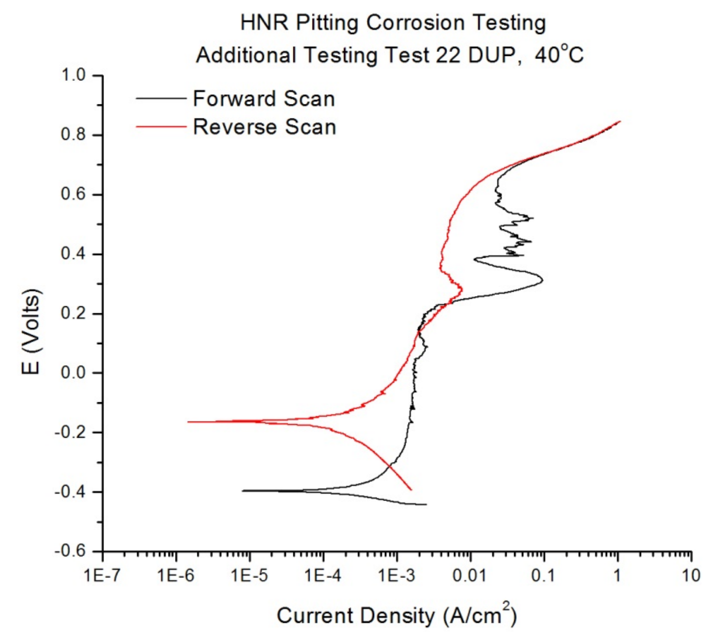
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 22a/b	2/09/16

Prepared by: Mau VS Date: 3/1/16 Reviewer: R. W

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 22





SRNL

Pitting Corrosion Testing, Task 3

Test ID **23**

This formula will make **1.4** Liters

Date: 2/09/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5667
2	Sodium Fluoride	0.1764	0.1773
3	Sodium Chloride	4.9090	4.9085
4	Sodium Nitrite	96.5930	96.6057
5	Sodium Sulfate	19.8982	19.8945
6	Sodium Phosphate, Tribasic 12	2.6608	2.6593
7	Sodium Carbonate	2.9677	2.9681
8	Sodium Citrate	14.6222	14.6319
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	118.9930	118.9829

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.98 Temp: °C

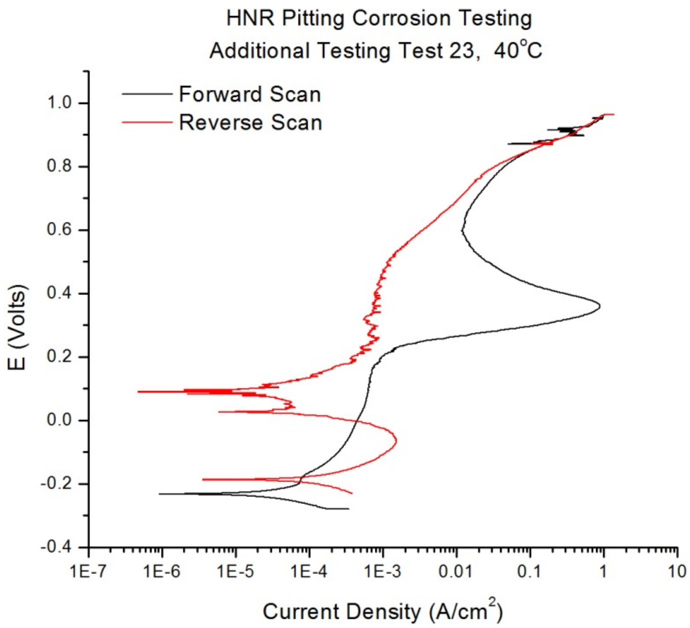
Comments/Notes:

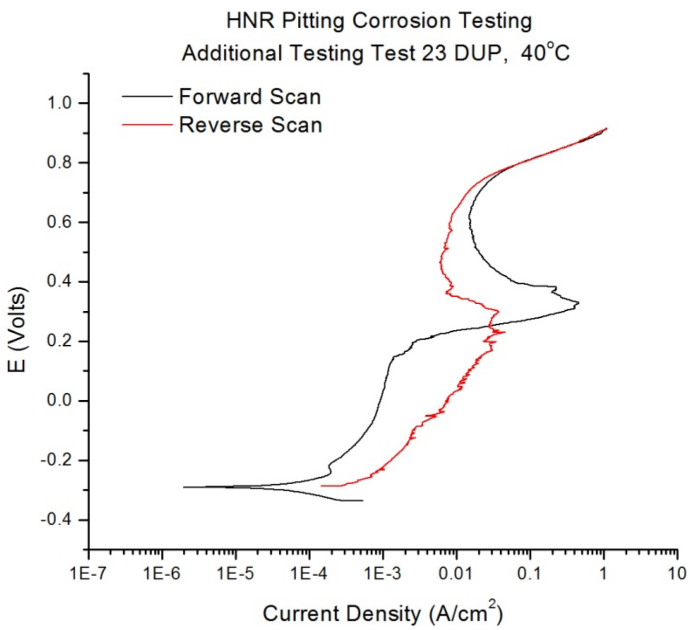
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 23a/b	2/09/16

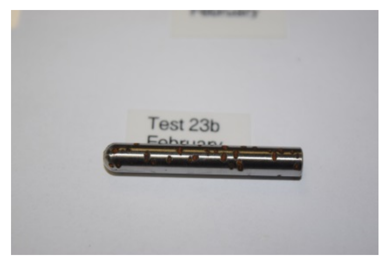
Prepared by: Mary VS Date: 3/1/16 Reviewer: [signature]

Date Printed 2/3/2016

Cyclic Potentiodynamic Polarization Test 23







SRNL

Pitting Corrosion Testing, Task 3

Test ID **24**

This formula will make **1.4** Liters

Date: 2/09/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5609
2	Sodium Fluoride	0.5878	0.5865
3	Sodium Chloride	32.7264	32.7198
4	Sodium Nitrite	144.8895	144.8892
5	Sodium Sulfate	19.8982	19.8985
6	Sodium Phosphate, Tribasic 12	5.3217	5.3225
7	Sodium Carbonate	29.6772	29.7310
8	Sodium Citrate	14.6222	14.6213
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	118.9930	118.9891

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0000

Record pH: 11.98 Temp: °C

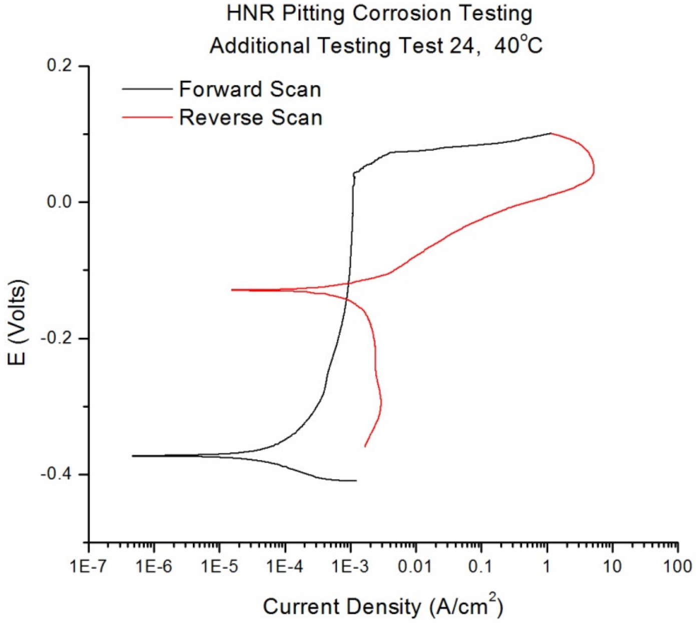
Comments/Notes:

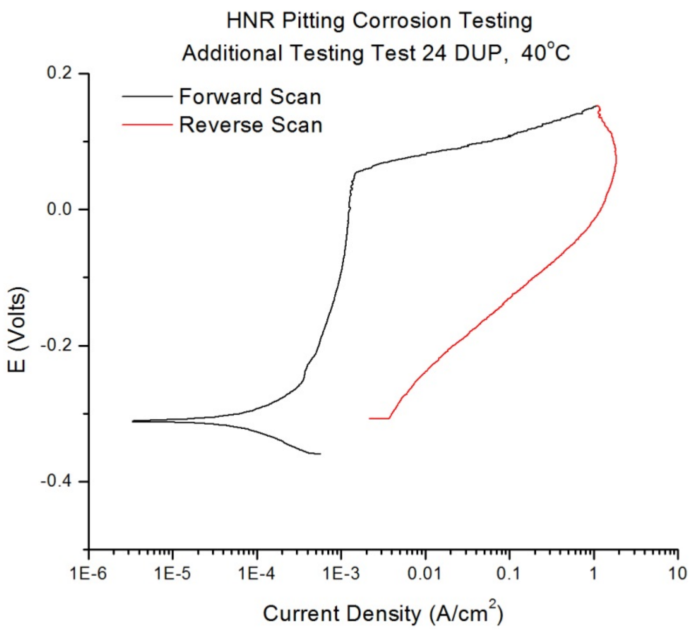
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
JD2232	Test 24a/b	2/09/16

Prepared by: Matt [signature] Date: 2/09/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 24





SRNL

Pitting Corrosion Testing, Task 3

Test ID **25**

This formula will make **1.4** Liters

Date: 2/09/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5661
2	Sodium Fluoride	0.1764	0.1744
3	Sodium Chloride	4.9090	4.9073
4	Sodium Nitrite	96.5930	96.5922
5	Sodium Sulfate	19.8982	19.8963
6	Sodium Phosphate, Tribasic 12	2.6608	2.6629
7	Sodium Carbonate	29.6772	29.6779
8	Sodium Citrate	14.6222	14.6233
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	178.4895	178.4835

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.99 Temp: °C

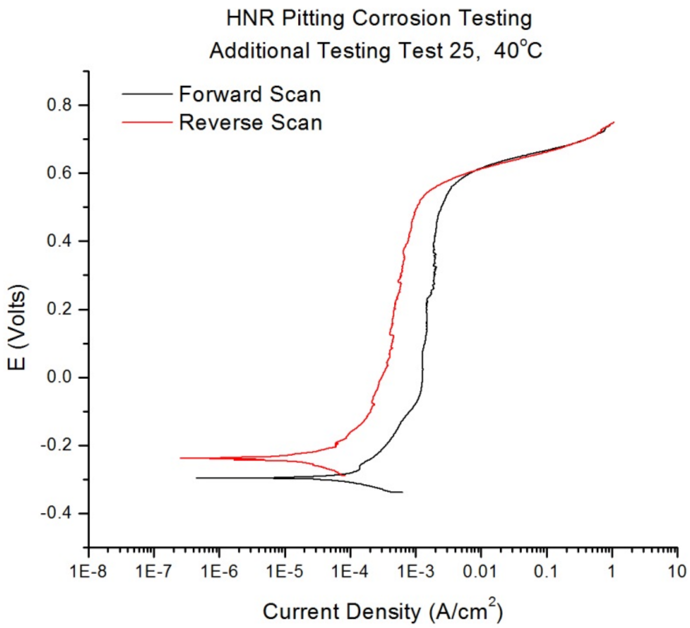
Comments/Notes:

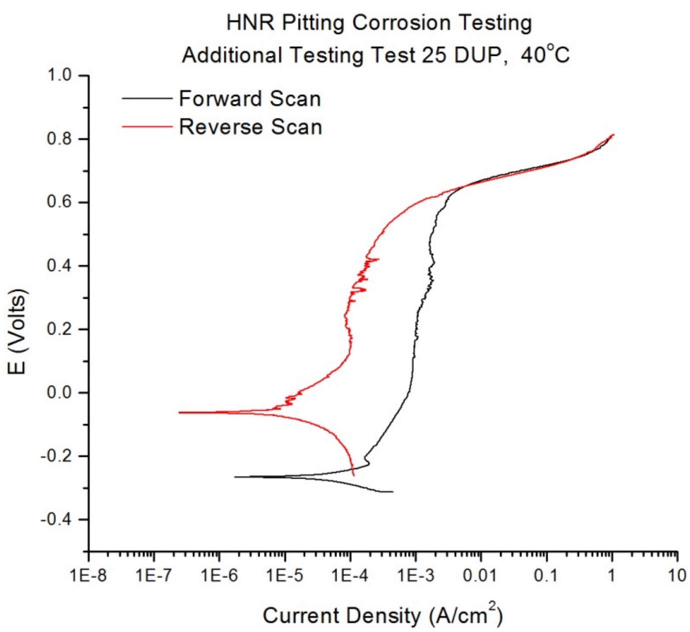
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 25a/b	2/09/16

Prepared by: [signature] Date: 2/09/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 25





SRNL

Pitting Corrosion Testing, Task 3

Test ID **26**

This formula will make **1.4** Liters

Date: 2/10/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5597
2	Sodium Fluoride	0.1764	0.1735
3	Sodium Chloride	32.7264	32.7251
4	Sodium Nitrite	144.8895	144.8997
5	Sodium Sulfate	0.9949	0.9951
6	Sodium Phosphate, Tribasic 1:	5.3217	5.3279
7	Sodium Carbonate	2.9677	2.9601
8	Sodium Citrate	14.6222	14.6217
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	178.4895	178.48861

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.96 Temp: °C

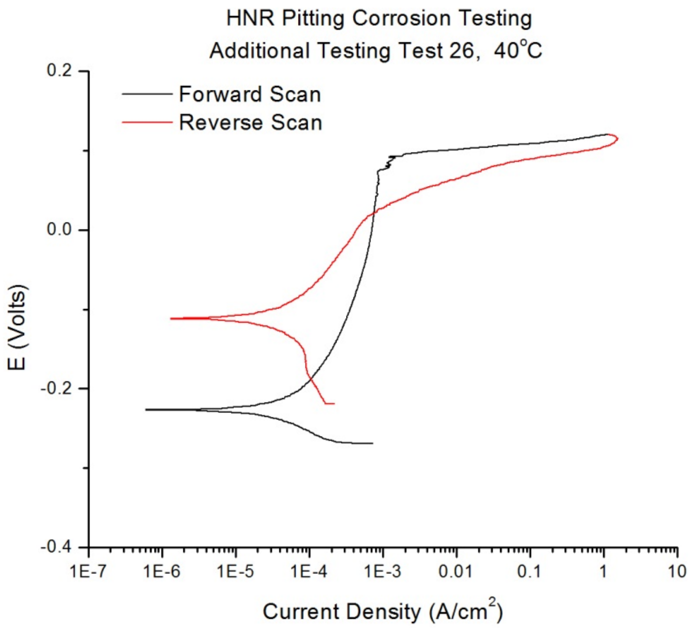
Comments/Notes:

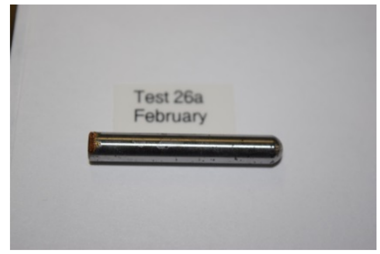
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
I02232	Tcs- 26 a 16	2/10/16

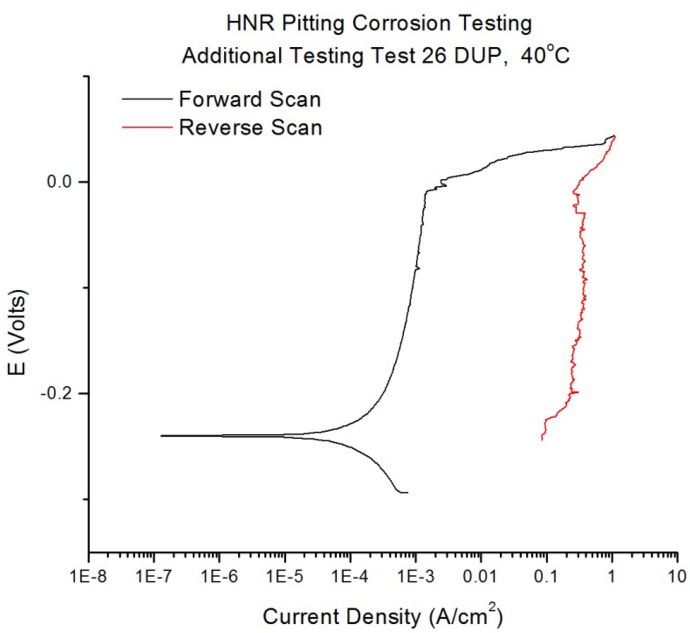
Prepared by: Matt VS Date: 2/10/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 26







SRNL

Pitting Corrosion Testing, Task 3

Test ID **27**

This formula will make **1.4** Liters

Date: 2/10/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5662
2	Sodium Fluoride	0.5878	0.5762
3	Sodium Chloride	32.7264	32.7259
4	Sodium Nitrite	193.1860	193.1843
5	Sodium Sulfate	0.9949	0.9837
6	Sodium Phosphate, Tribasic 12	5.3217	5.4105
7	Sodium Carbonate	29.6772	29.6813
8	Sodium Citrate	14.6222	14.6229
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	178.4895	178.4875

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.99 Temp: °C

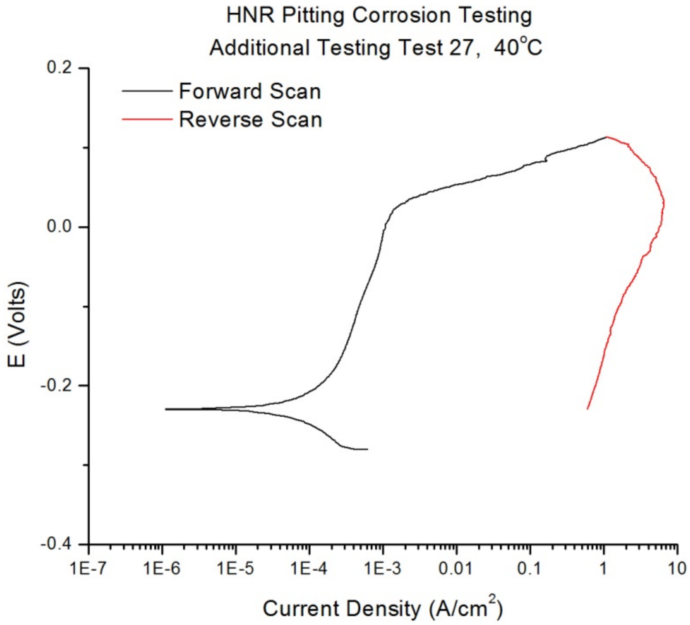
Comments/Notes:

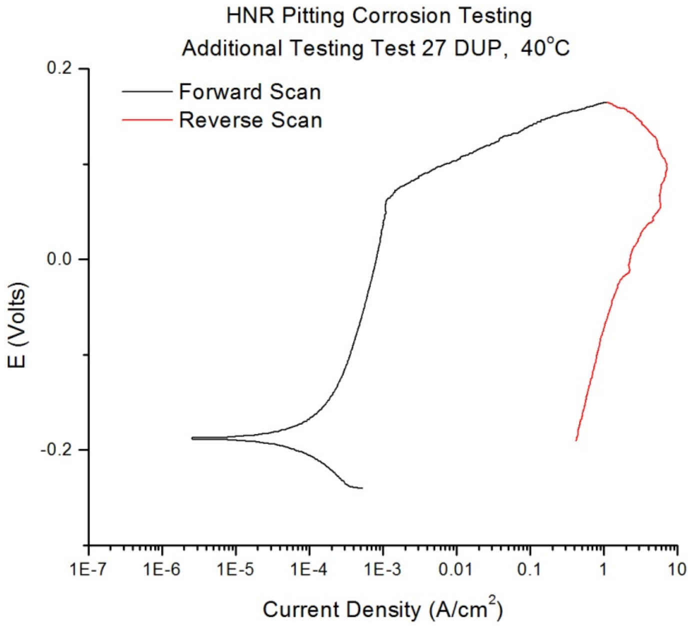
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 27a16	2/10/16

Prepared by: Matt VS Date: 2/10/16 Reviewer: R. U[illegible]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 27





SRNL

Pitting Corrosion Testing, Task 3

Test ID **28**

This formula will make **1.4** Liters

Date: 2/10/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5573
2	Sodium Fluoride	0.5878	0.5871
3	Sodium Chloride	4.9090	4.9113
4	Sodium Nitrite	96.5930	96.5891
5	Sodium Sulfate	19.8982	19.9108
6	Sodium Phosphate, Tribasic 12	2.6608	2.6613
7	Sodium Carbonate	29.6772	29.6694
8	Sodium Citrate	14.6222	14.6271
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	237.9860	237.9825

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.99 Temp: °C

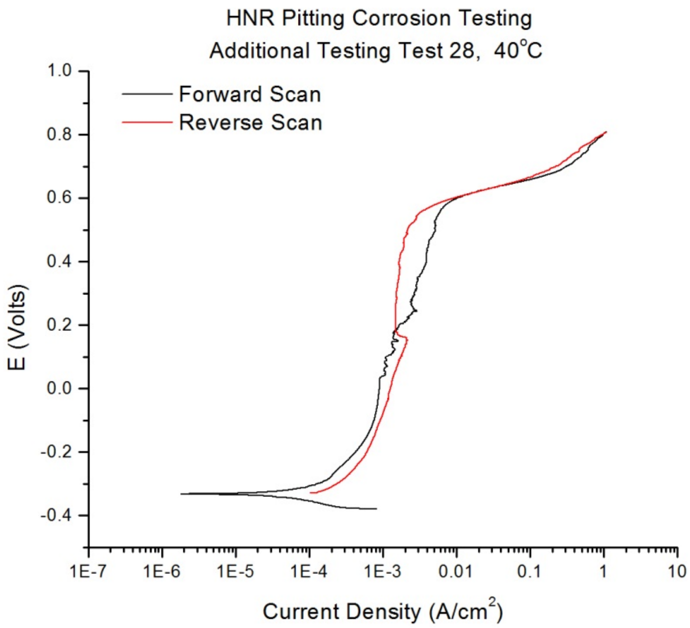
Comments/Notes:

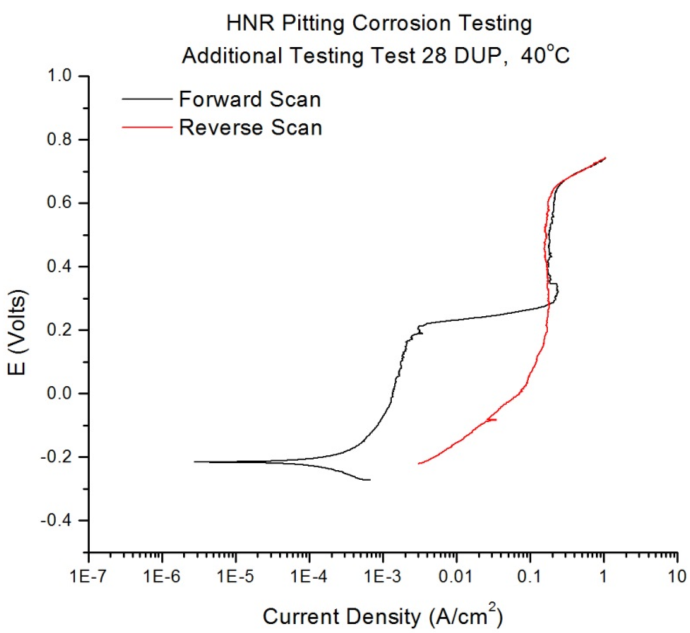
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	Test 28a/b	2/10/16

Prepared by: Mayr VS Date: 2/10/16 Reviewer: [signature]

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 28





SRNL

Pitting Corrosion Testing, Task 3

Test ID **29**

This formula will make **1.4** Liters

Date: 2/10/16 Batch no.: 4

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5613
2	Sodium Fluoride	0.5878	0.5763
3	Sodium Chloride	32.7264	32.7234
4	Sodium Nitrite	144.8895	144.8870
5	Sodium Sulfate	0.9949	0.9932
6	Sodium Phosphate, Tribasic 1:	5.3217	5.3243
7	Sodium Carbonate	2.9677	2.9672
8	Sodium Citrate	14.6222	14.6197
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	237.9860	237.9662

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.98 Temp: °C

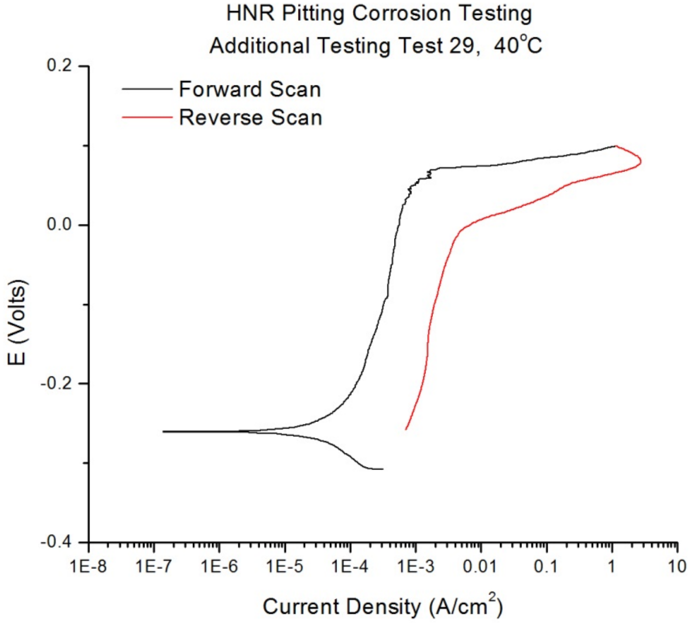
Comments/Notes:

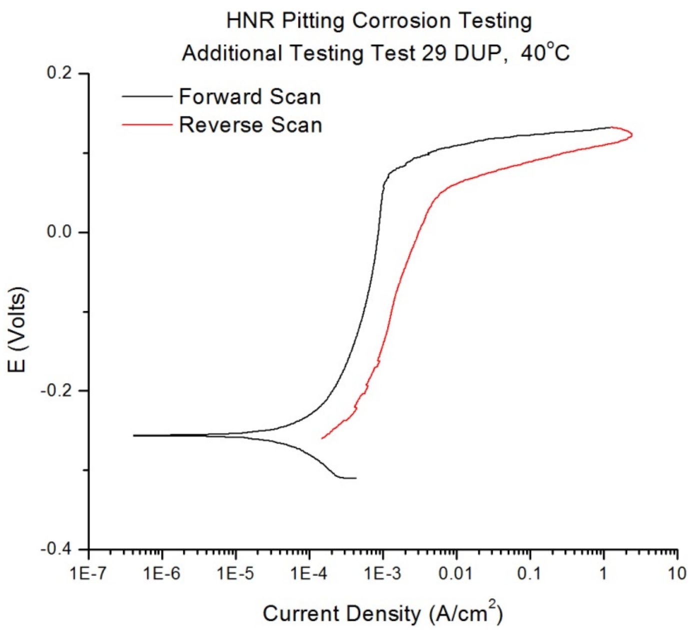
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID2232	EH Test 29a/b	2/10/16

Prepared by: Matt VS Date: 2/10/16 Reviewer: R. Wy

Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test 29





SRNL

Pitting Corrosion Testing, Task 3

Test ID **30**

This formula will make **1.4** Liters

Date: 2/11/16 Batch no.: 1

Start with about 50% of the total volume of distilled water to a 2-L beaker.

Starting water: 700 mL

		Target weight, g	
1	Sodium Hydroxide	0.5600	0.5612
2	Sodium Fluoride	0.1764	0.1673
3	Sodium Chloride	4.9090	4.9112
4	Sodium Nitrite	193.1860	193.1871
5	Sodium Sulfate	19.8982	19.8979
6	Sodium Phosphate, Tribasic 12	2.6608	2.6632
7	Sodium Carbonate	2.9677	2.9673
8	Sodium Citrate	14.6222	14.6248
9	Sodium Chromate	0.0000	0
10	Sodium Nitrate	237.9860	237.9881

12 Add water to make the volume in the beaker about 1200mL

13 Transfer to Volumetric Flask and dilute to the volume mark.

14 Homogenize solution.

Check pH Target pH 12.0

Record pH: 11.99 Temp: °C

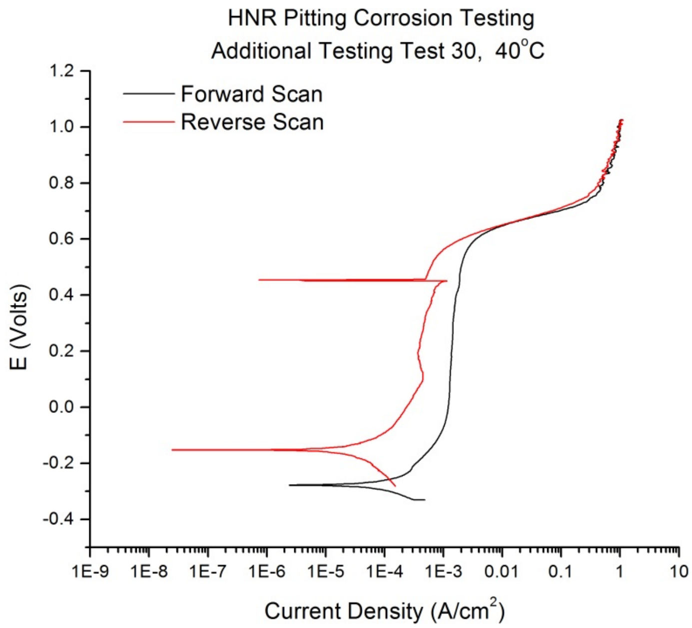
Comments/Notes:

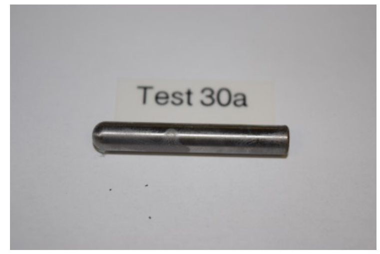
CPP Testing	Test Temperature:	
Coupon ID	File name	Date
ID 2232	Test 30a/b	2/11/16

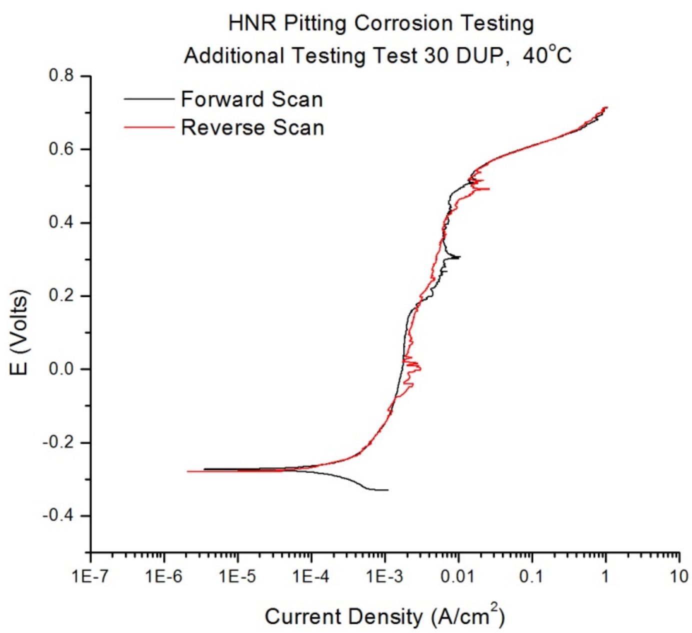
Prepared by: Matt Van [signature] Date: 2/11/16 Reviewer: R. [signature]

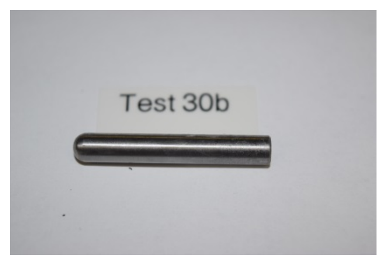
Date Printed(2/3/2016

Cyclic Potentiodynamic Polarization Test30









Appendix G

Chemical Composition of Simulants used in Waste Buffering (Task 4) with Electrochemical Results and Pictures after Test

Original Table with the experiments using Original Simulant

Test	Temperature (°C)	Nitrate (M)	Nitrite (M)	Hydroxide (M)
1	40	1.1	0.5	0.01
2	40	1.1	1	0.01
3	40	1.1	1.5	0.01
4	40	1.1	0.5	0.05
5	40	1.1	1	0.05
6	40	1.1	1.5	0.05
7	40	3	0.5	0.01
8	40	3	1	0.01
9	40	3	1.5	0.01
10	40	3	0.5	0.05
11	40	3	1	0.05
12	40	3	1.5	0.05
13	40	5.5	0.5	0.01
14	40	5.5	1	0.01
15	40	5.5	1.5	0.01
16	40	5.5	0.5	0.05
17	40	5.5	1	0.05
18	40	5.5	1.5	0.05

Simulants with High Aluminum Nitrate Concentration (Original simulant)

Summary of Tests

Test	Temperature (°C)	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	Hysteresis	Pitting on Sample?
7	40	3	0.5	0.01	12.12	Pos/Mixed	Major
8	40	3	1	0.01	11.54	Negative	Minor
9	40	3	1.5	0.01	12.4	Negative	None
10	40	3	0.5	0.05	12.57	Mixed	Minor
11	40	3	1	0.05	12.3	Negative	None
12	40	3	1.5	0.05	12.13	Negative	None
13	40	5.5	0.5	0.01	12.41	Mixed	Major

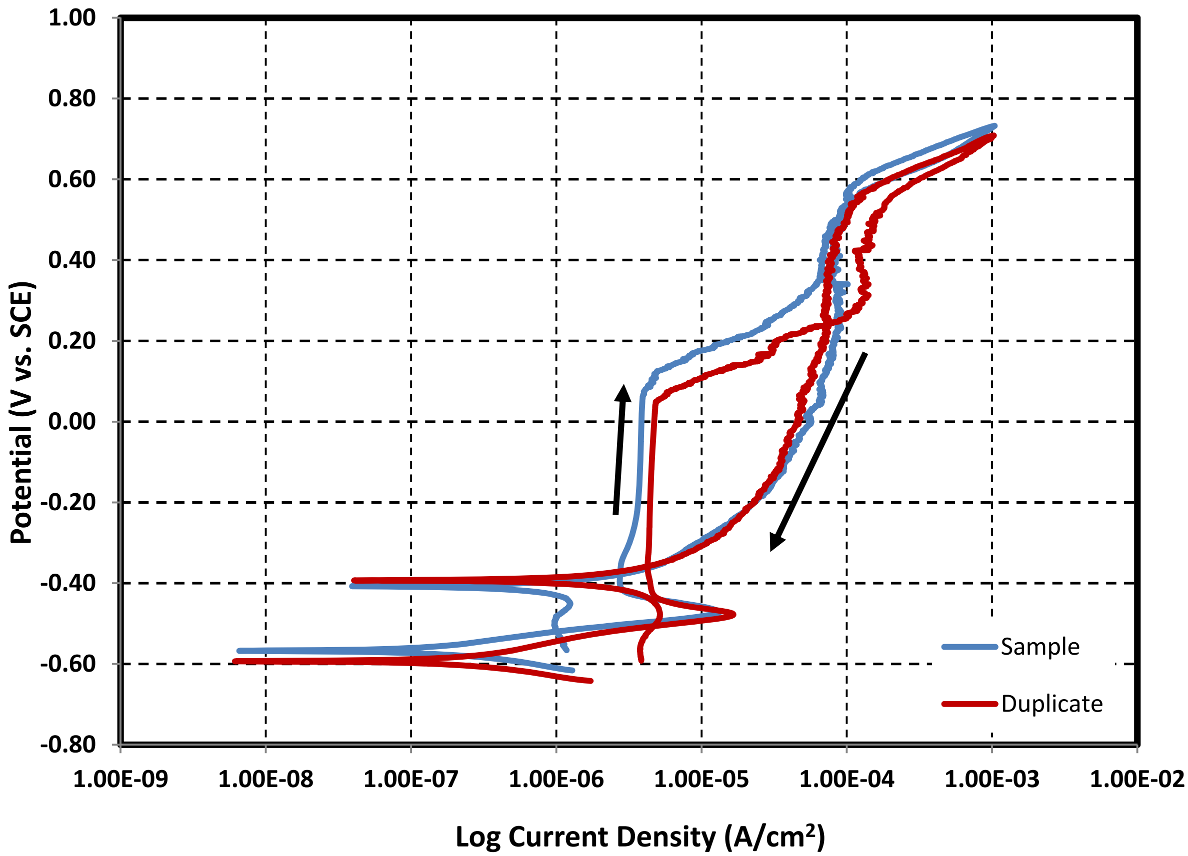
Composition of simulant for waste buffering-Test 7

Test 7

Temperature	40	°C		
pH	12.49	at room temp.	12.09	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	NaCl	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	NaOH	40.0000	2.939	164.5840
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	0.5	48.3000

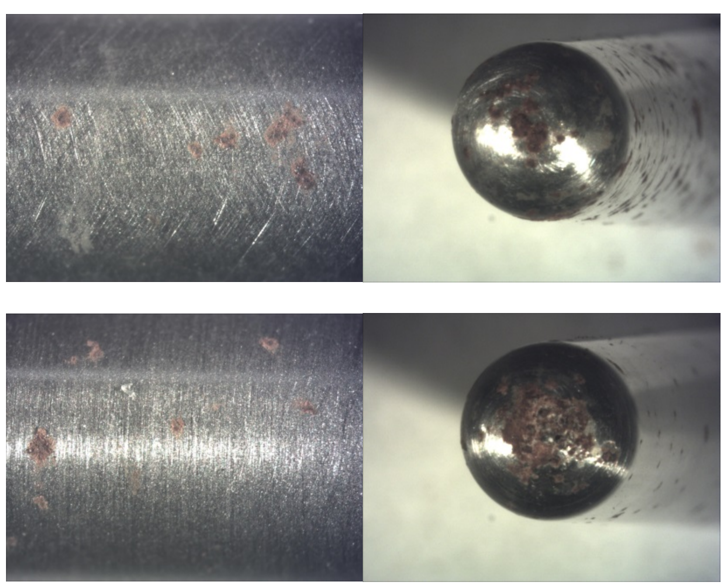
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 7

Test 7D



Shank (20X) **Nose (10X)**

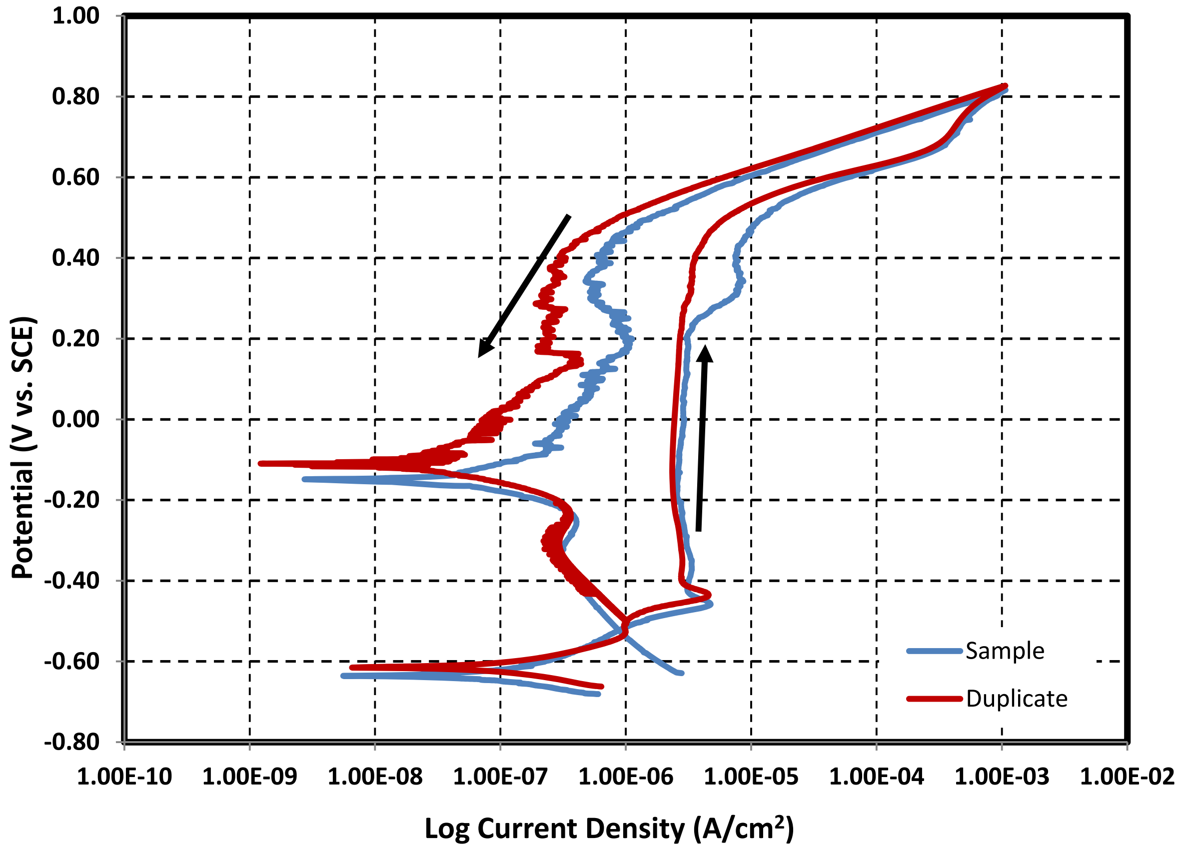
Composition of simulant for waste buffering-Test 8

Test 8

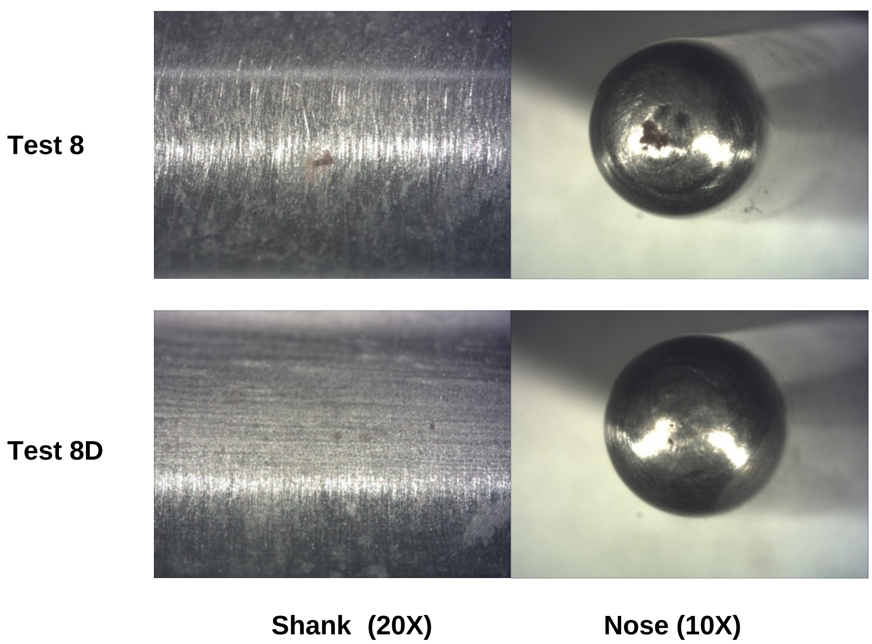
Temperature	40	°C		
pH	12.29	at room temp.	11.54	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	$NaCl$	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	$NaOH$	40.0000	2.939	164.5840
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	1	96.6000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



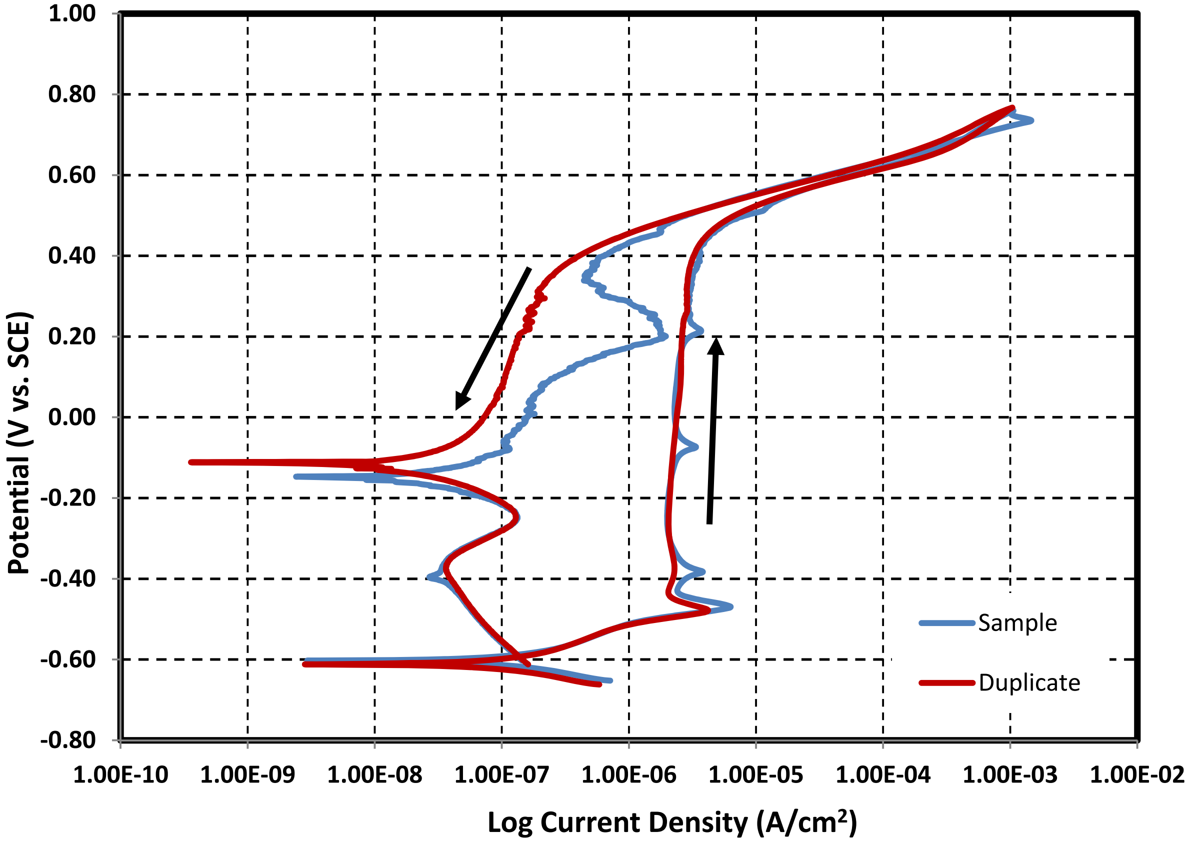
Composition of simulant for waste buffering-Test 9

Test 9

Temperature	40	°C		
pH	12.40	at room temp.	12.40	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	$NaCl$	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	$NaOH$	40.0000	2.939	164.5840
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	1.5	144.9000

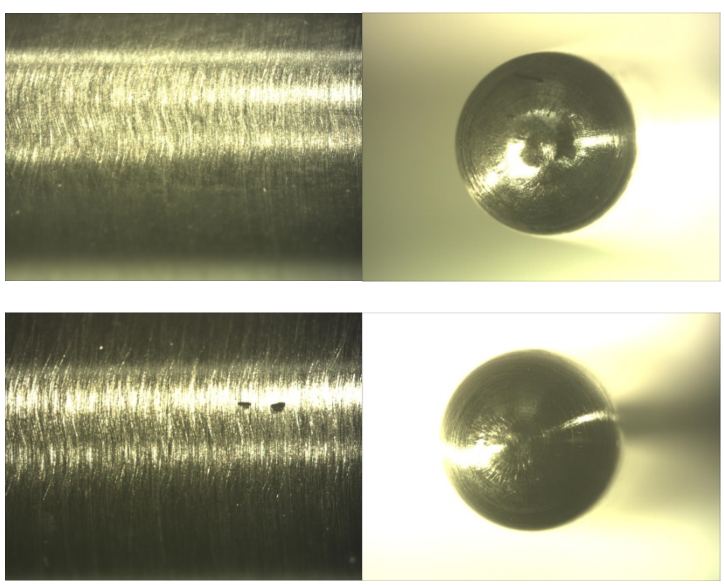
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 9

Test 9D



Shank (20X) **Nose (10X)**

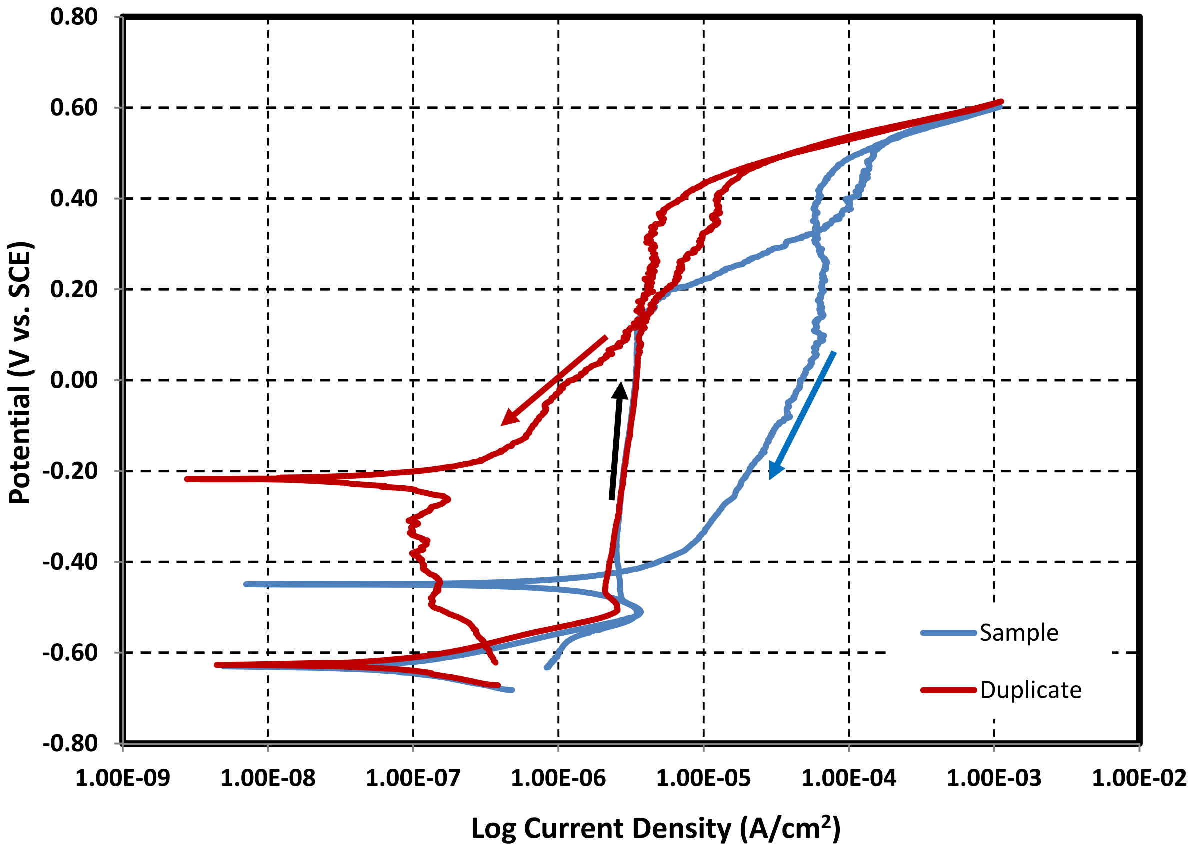
Composition of simulant for waste buffering-Test 10

Test 10

Temperature	40	°C		
pH	12.73	at room temp.	12.57	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	$NaCl$	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	$NaOH$	40.0000	2.979	166.8240
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	0.5	144.9000

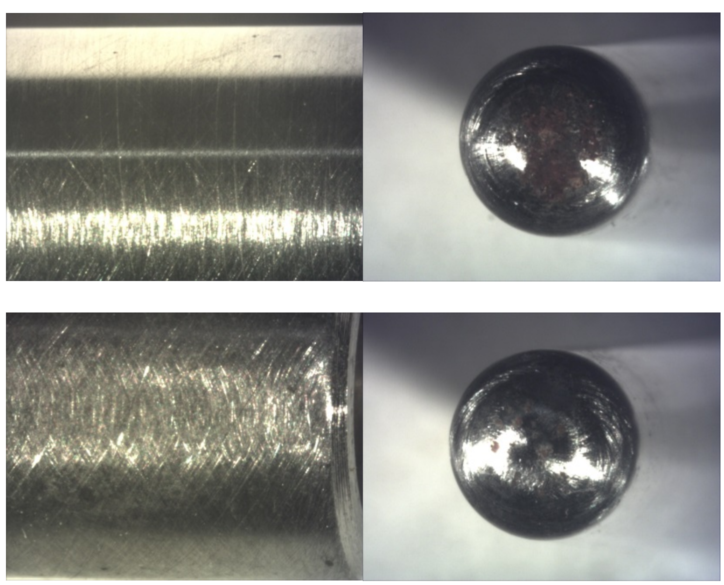
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 10

Test 10D



Shank (20X) **Nose (10X)**

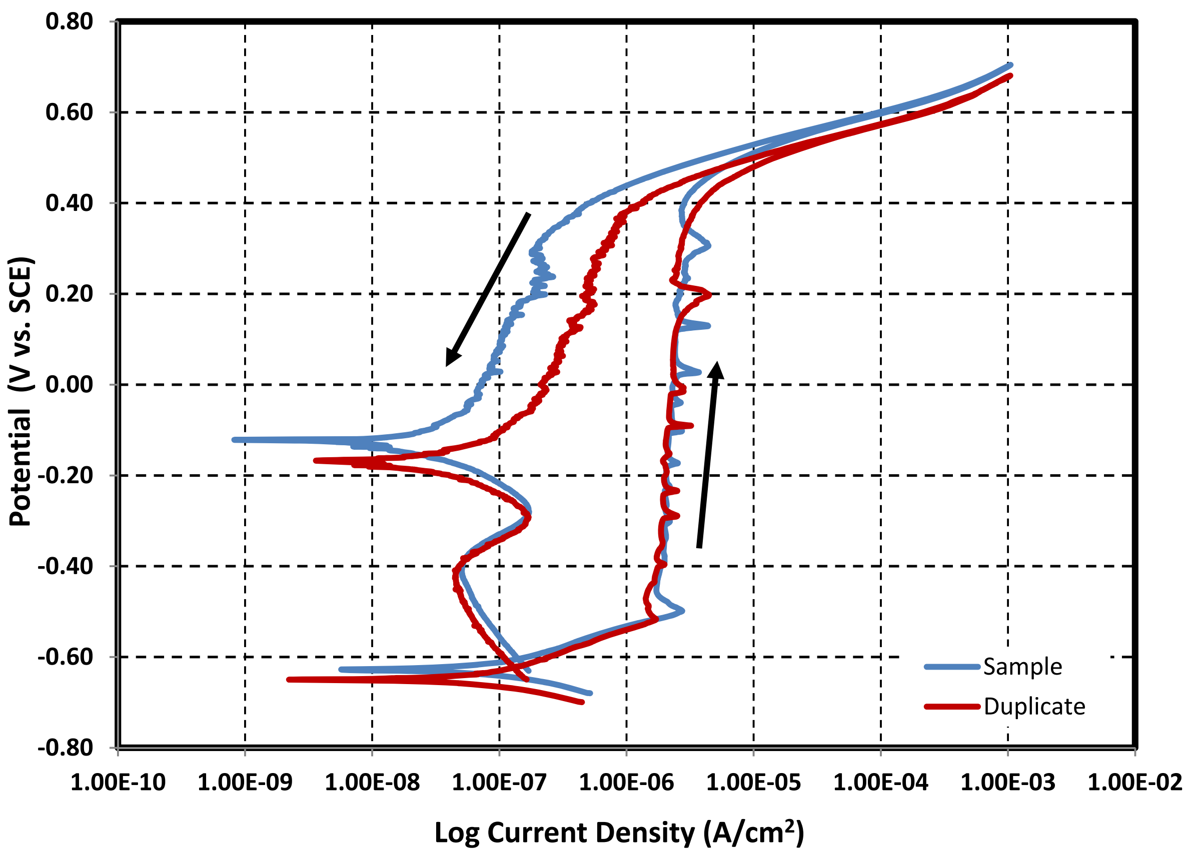
Composition of simulant for waste buffering-Test 11

Test 11

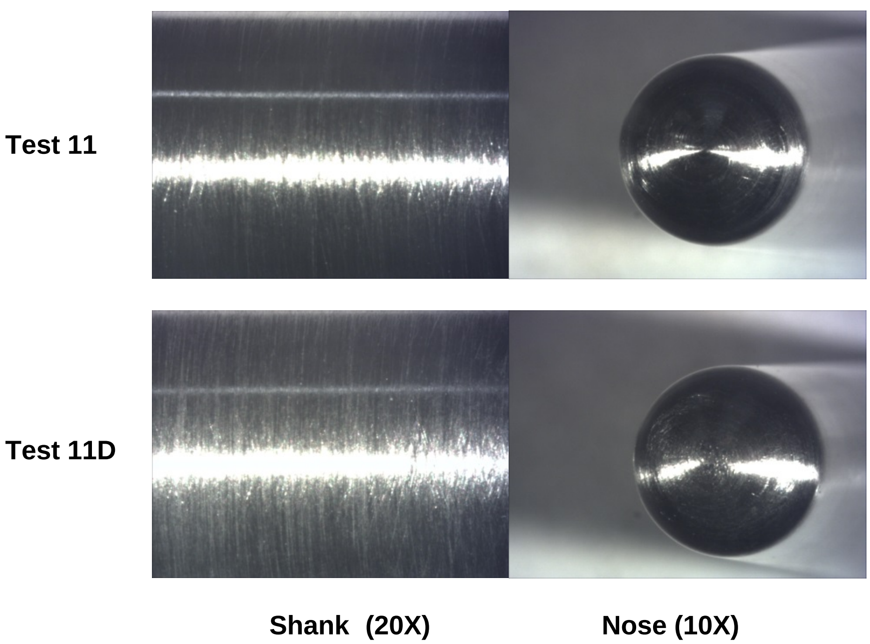
Temperature	40	°C		
pH	12.57	at room temp.	12.30	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	$NaCl$	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	$NaOH$	40.0000	2.979	166.8240
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	1.0	96.6000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



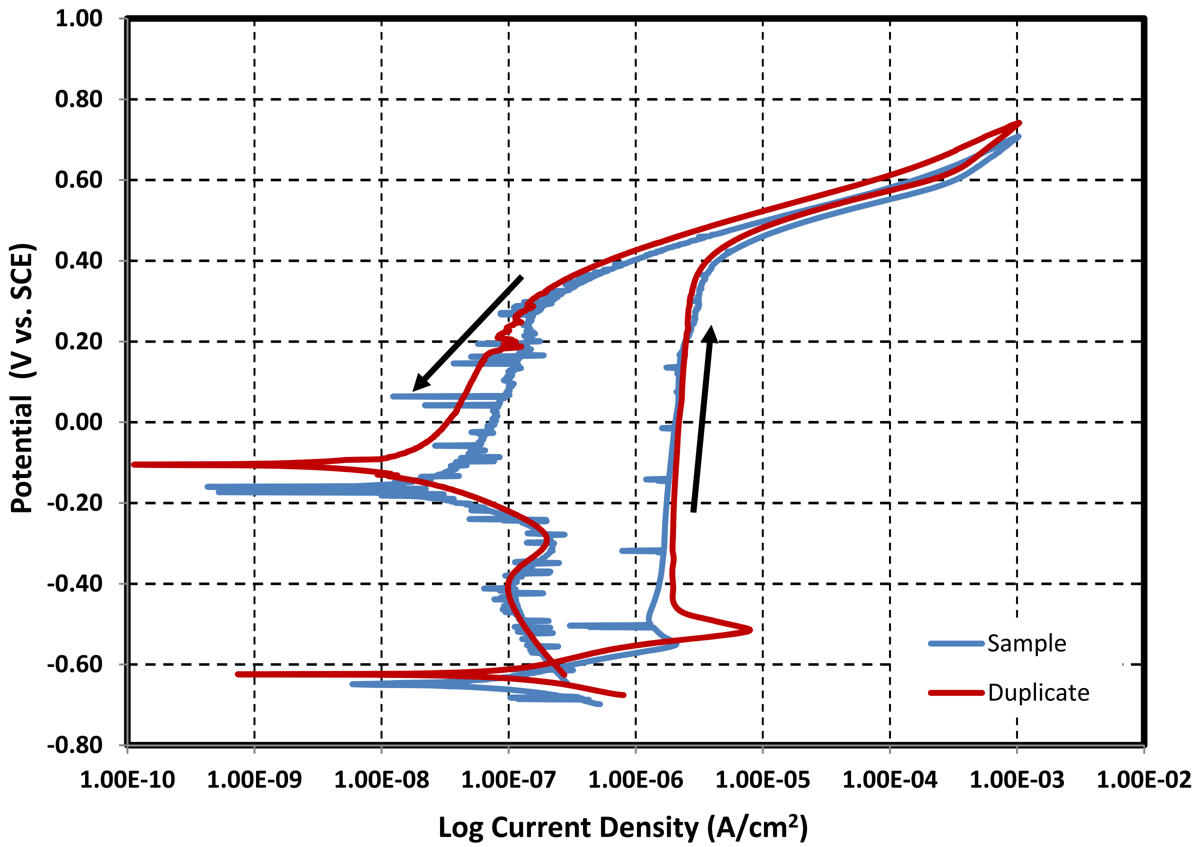
Composition of simulant for waste buffering-Test 12

Test 12

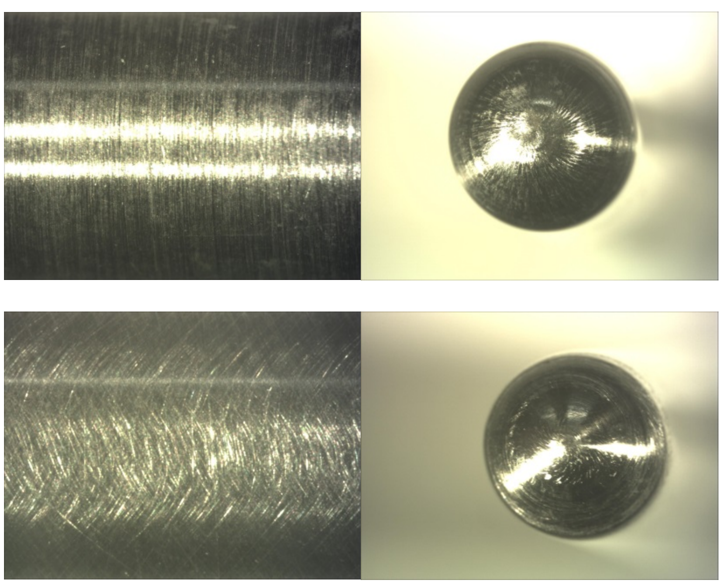
Temperature	40	°C
pH		at room temp.	at exp. temp.
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	NaCl	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	NaOH	40.0000	2.979	166.8240
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.426	169.6940
Sodium nitrite	$NaNO_2$	69.0000	1.5	144.9000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



Test 12

Test 12D

Shank (20X) **Nose (10X)**

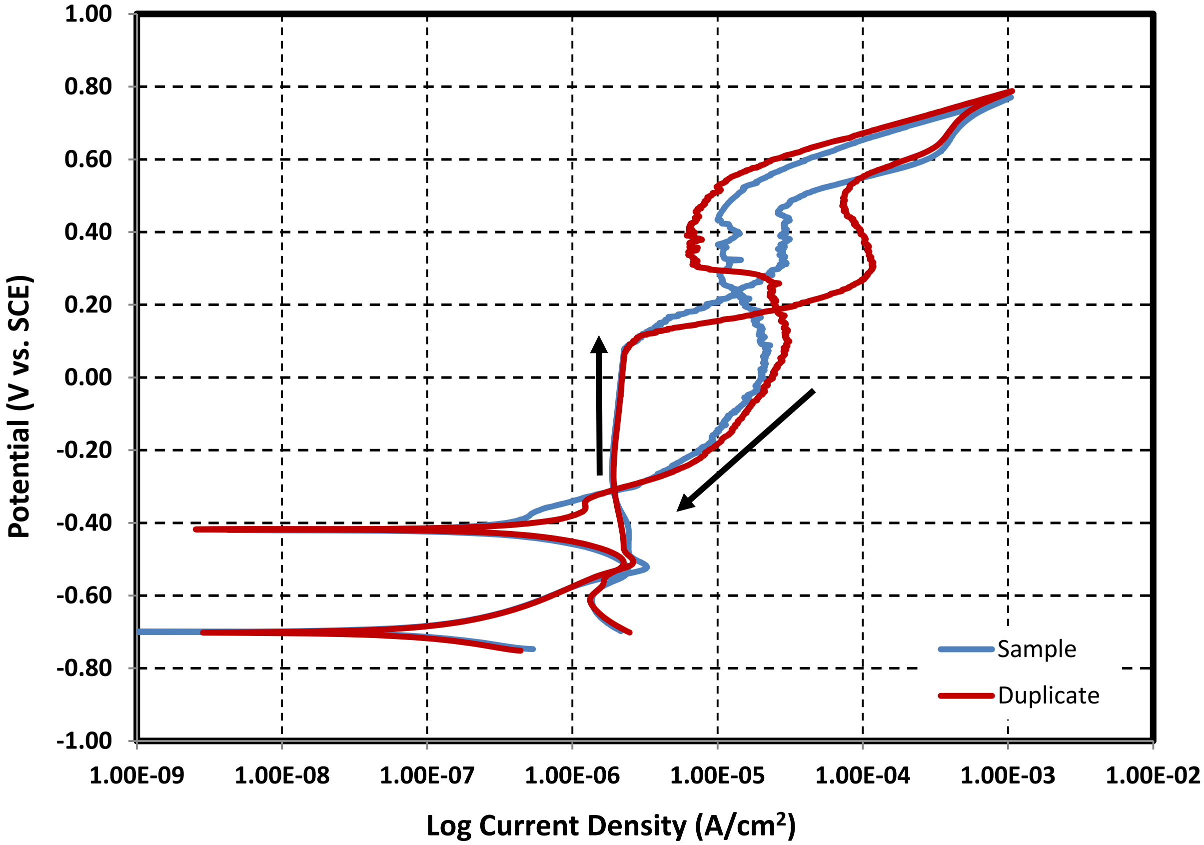
Composition of simulant for waste buffering-Test 13

Test 13

Temperature	40	°C		
pH	12.76	at room temp.	12.40	at exp. temp.
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	0.497	260.9250
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	0.000553	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	0.01	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	0.000375	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	0.000575	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	0.0000864	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	0.000656	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	0.000324	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	0.00675	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	0.0464	6.5610
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	0.048108	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	0.01899	7.3909
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	0.02532	7.7277
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	0.111408	32.7540
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	0.007596	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	0.112674	20.9799
Sodium chloride	$NaCl$	58.4000	0.106	8.6666
Sodium sulfate	Na_2SO_4	142.0000	0.128	25.4464
Ammonium Chloride	NH_4Cl	55.4920	0.00498	0.3869
Glycolic acid	$C2H_4O_3$	76.1000	0.161	17.1529
Sodium hydroxide	$NaOH$	40.0000	0.934	52.3040
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	0.0514	27.3448
Sodium formate	$Na(CHO_2)$	68.0000	0.233	22.1816
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	0.0208	3.9603
Sodium carbonate	Na_2CO_3	106.0000	1.12	166.2080
Sodium nitrate	$NaNO_3$	85.0000	5.4	642.6000
Sodium nitrite	$NaNO_2$	69.0000	0.5	48.300

Cyclic Potentiodynamic Polarization



No images taken. Large pits were observed in the sample and duplicate.

Simulants with Low Aluminum Nitrate Concentration (Modified simulant)

Summary of Tests

With no pH adjustment

Test	Temperature (°C)	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	Hysteresis	Pitting on Sample?
1	40	1.1	0.5	0.01	11.04	Neg/Pos	Minor/Major
2	40	1.1	1	0.01	11.13	Negative	None
3	40	1.1	1.5	0.01	11.05	Negative	None
4	40	1.1	0.5	0.05	11.35	Negative	Minor
5	40	1.1	1	0.05	11.44	Negative	None
6	40	1.1	1.5	0.05	11.39	Negative	None
13	40	5.5	0.5	0.01	11.34	Mixed	Major

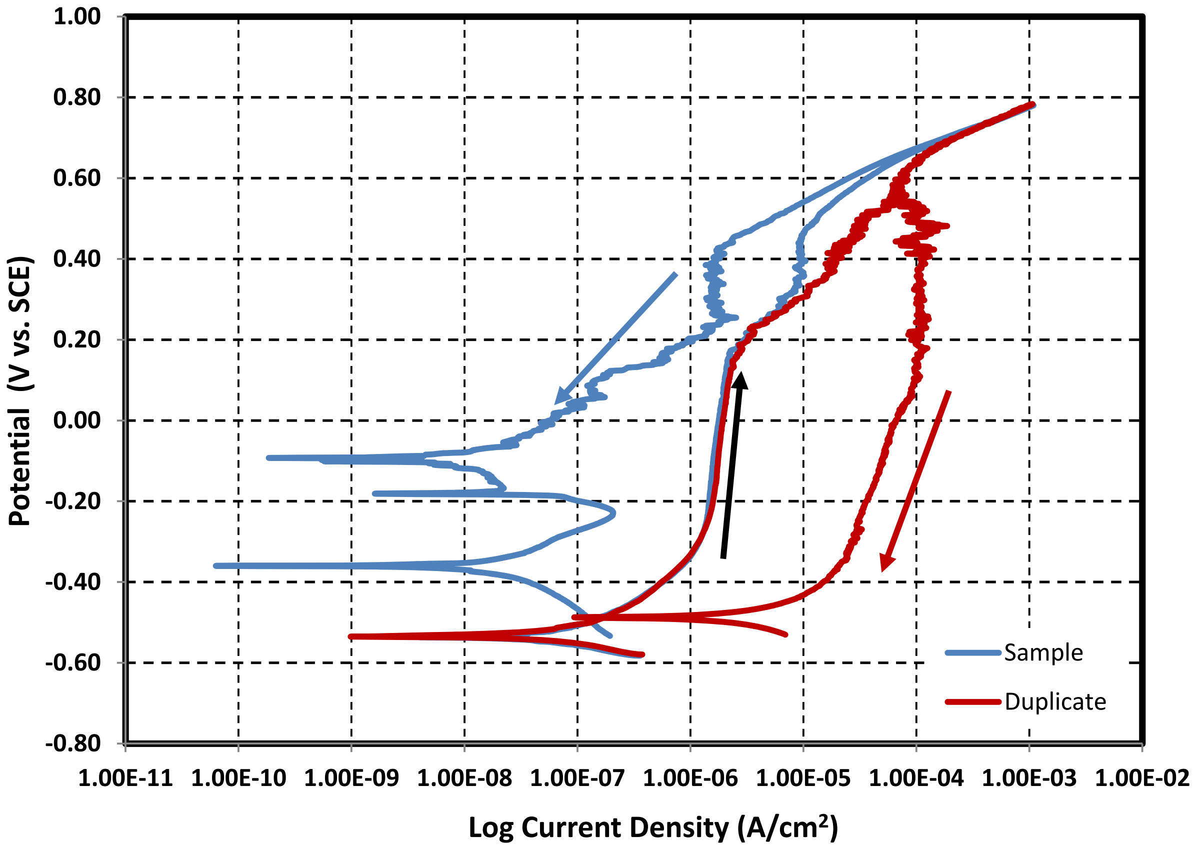
Composition of simulant for waste buffering-Test 1

Test 1

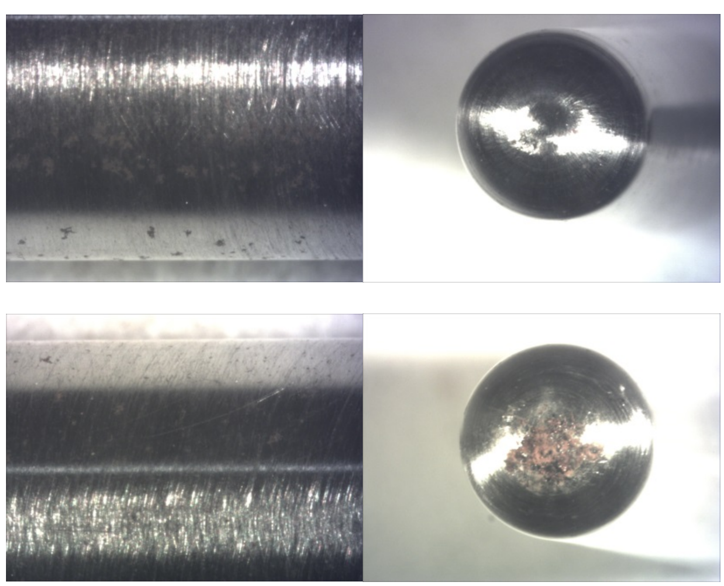
Temperature	40	°C
pH at temperature	11.04	
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



Test 1

Test 1D

Shank (20X) Nose (10X)

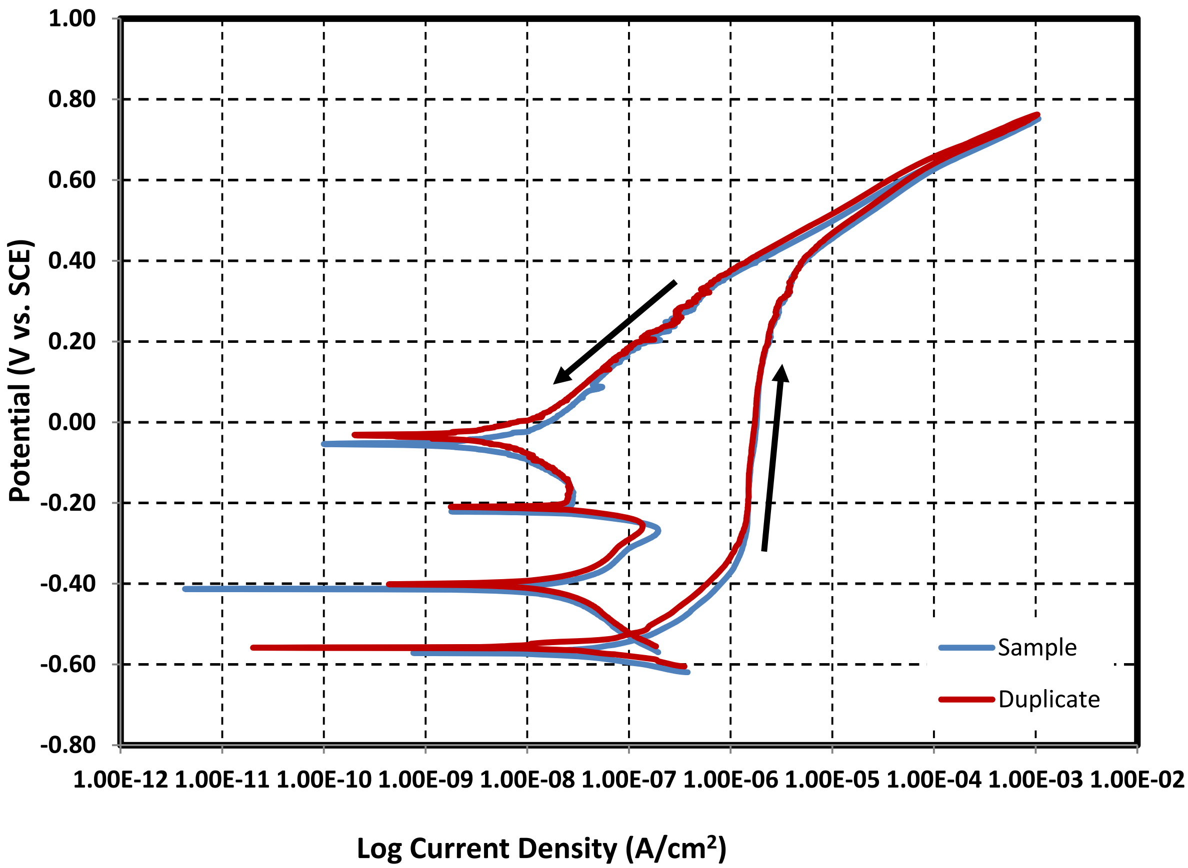
Composition of simulant for waste buffering-Test 2

Test 2

Temperature	40	°C
pH at temperature	11.13	
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

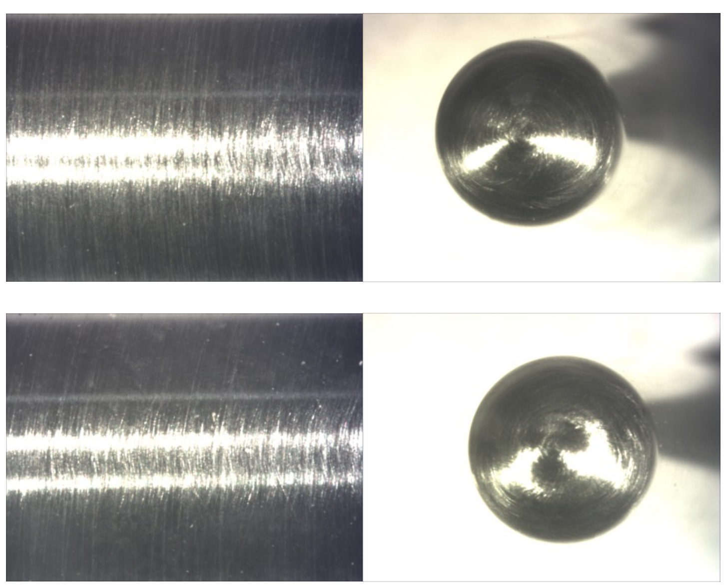
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 2

Test 2D



Shank (20X) **Nose (10X)**

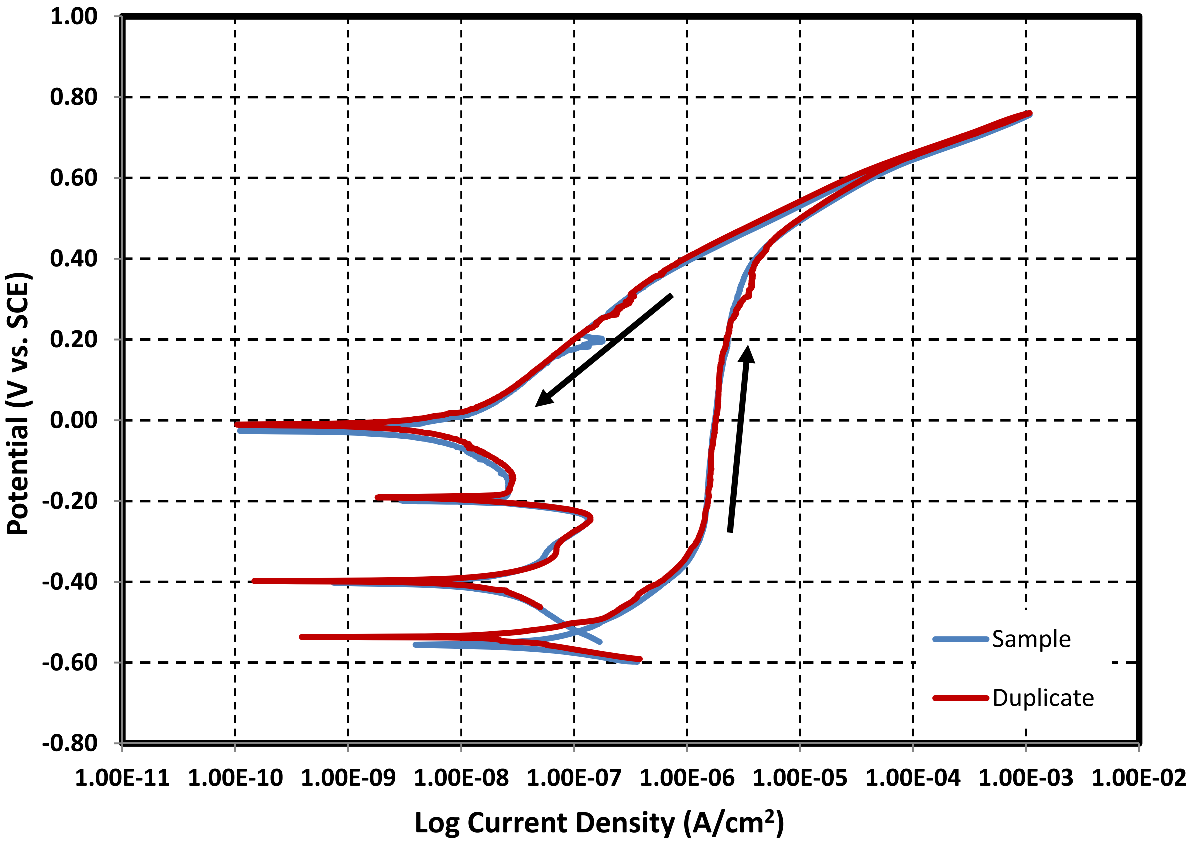
Composition of simulant for waste buffering-Test 3

Test 3

Temperature	40	°C
pH at temperature	11.05	
Volume	1.4	L

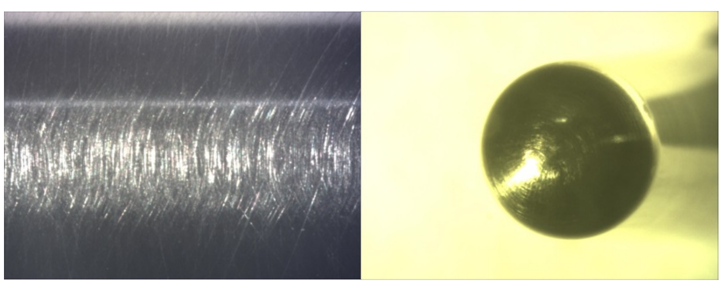
Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_{4.}12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

Cyclic Potentiodynamic Polarization

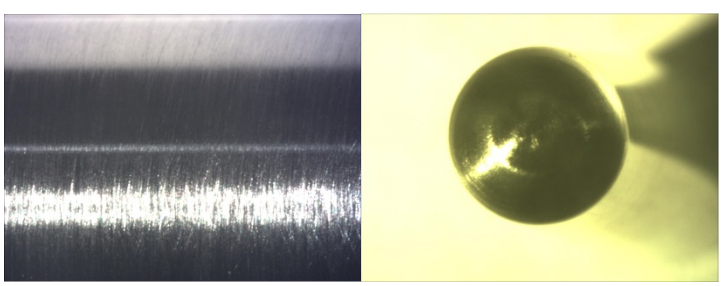


Images of bullet samples after electrochemical tests

Test 3



Test 3D



Shank (20X) Nose (10X)

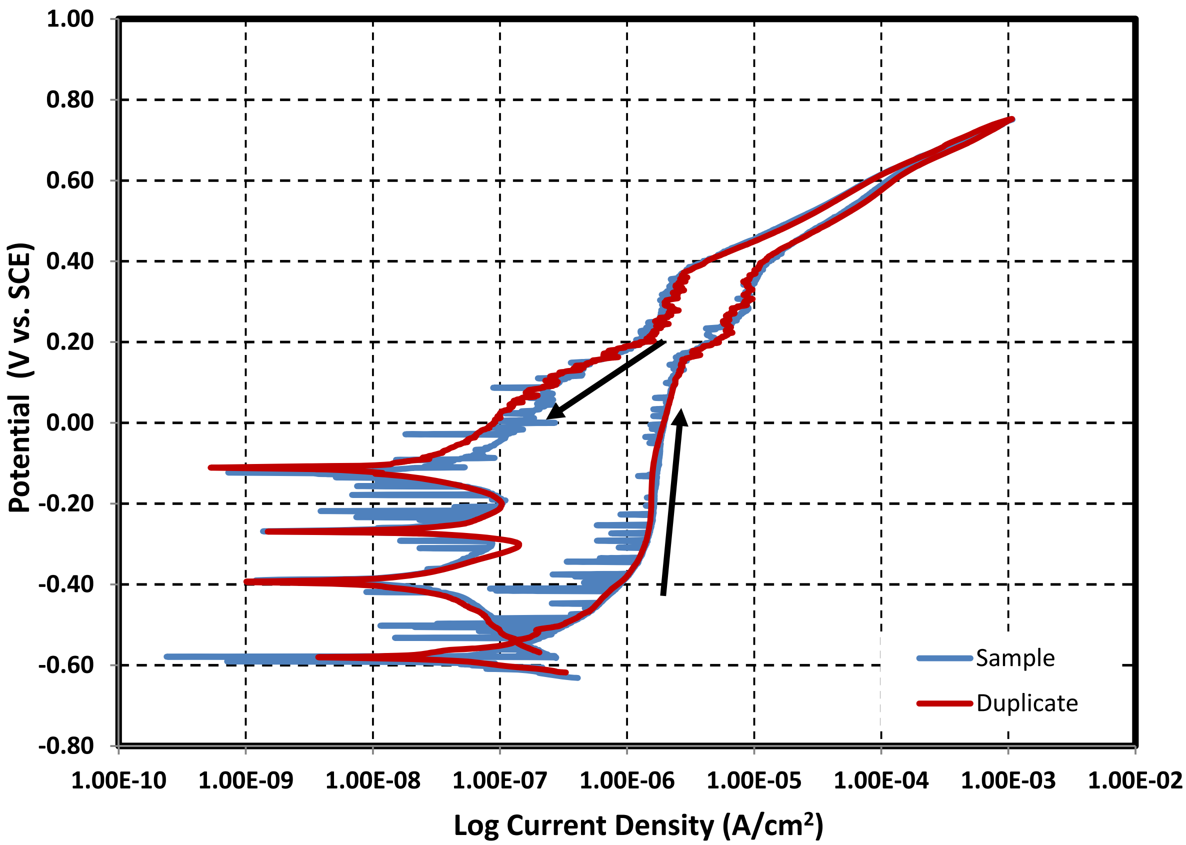
Composition of simulant for waste buffering-Test 4

Test 4

Temperature	40	°C
pH at temperature	11.35	
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

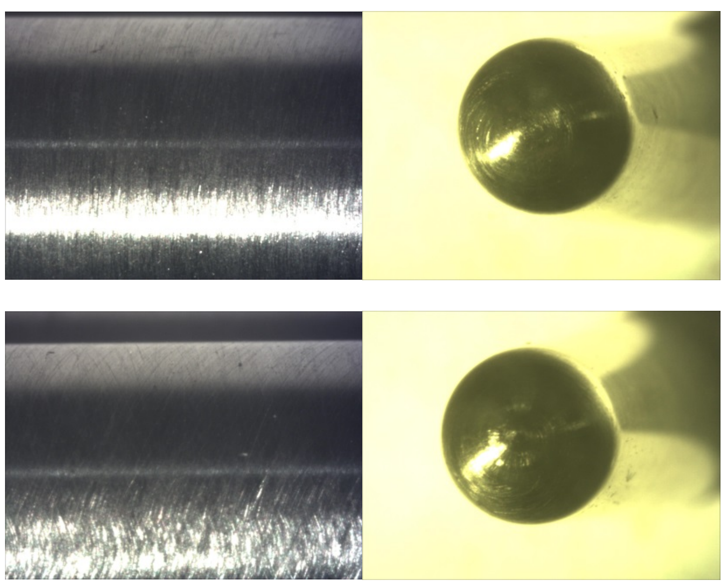
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 4

Test 4D



Shank (20X) Nose (10X)

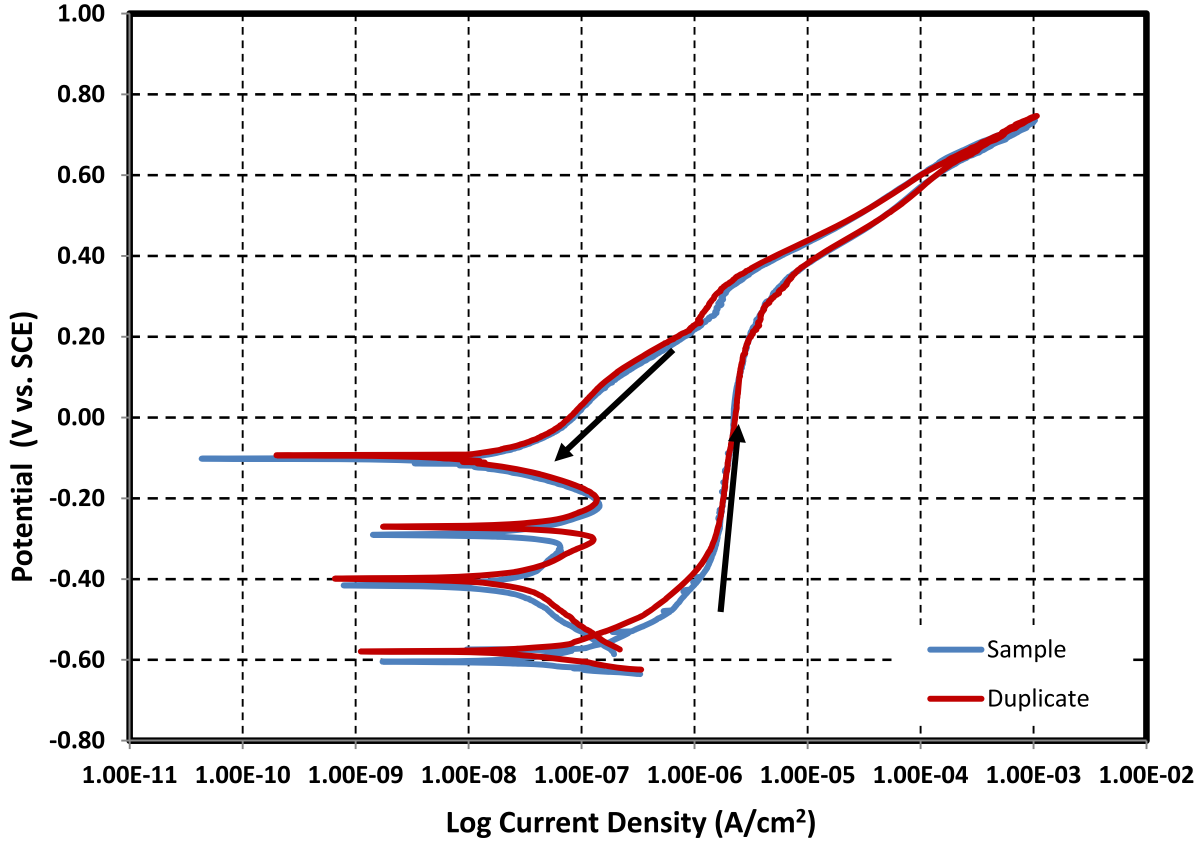
Composition of simulant for waste buffering-Test 5

Test 5

Temperature	40	°C
pH at temperature	11.44	
Volume	1.4	L

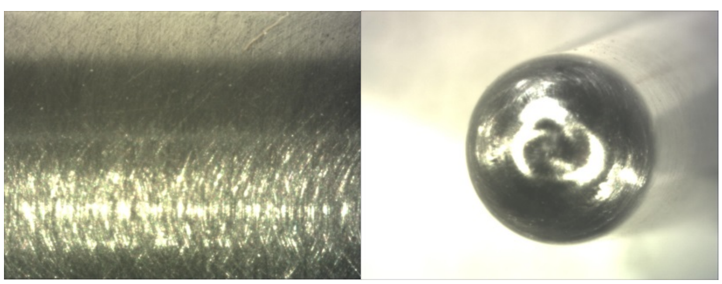
Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

Cyclic Potentiodynamic Polarization

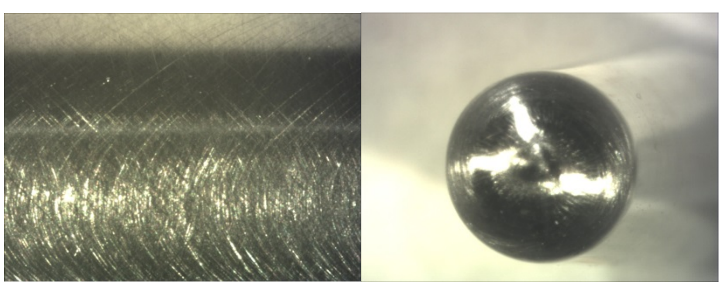


Images of bullet samples after electrochemical tests

Test 5



Test 5D



Shank (20X) Nose (10X)

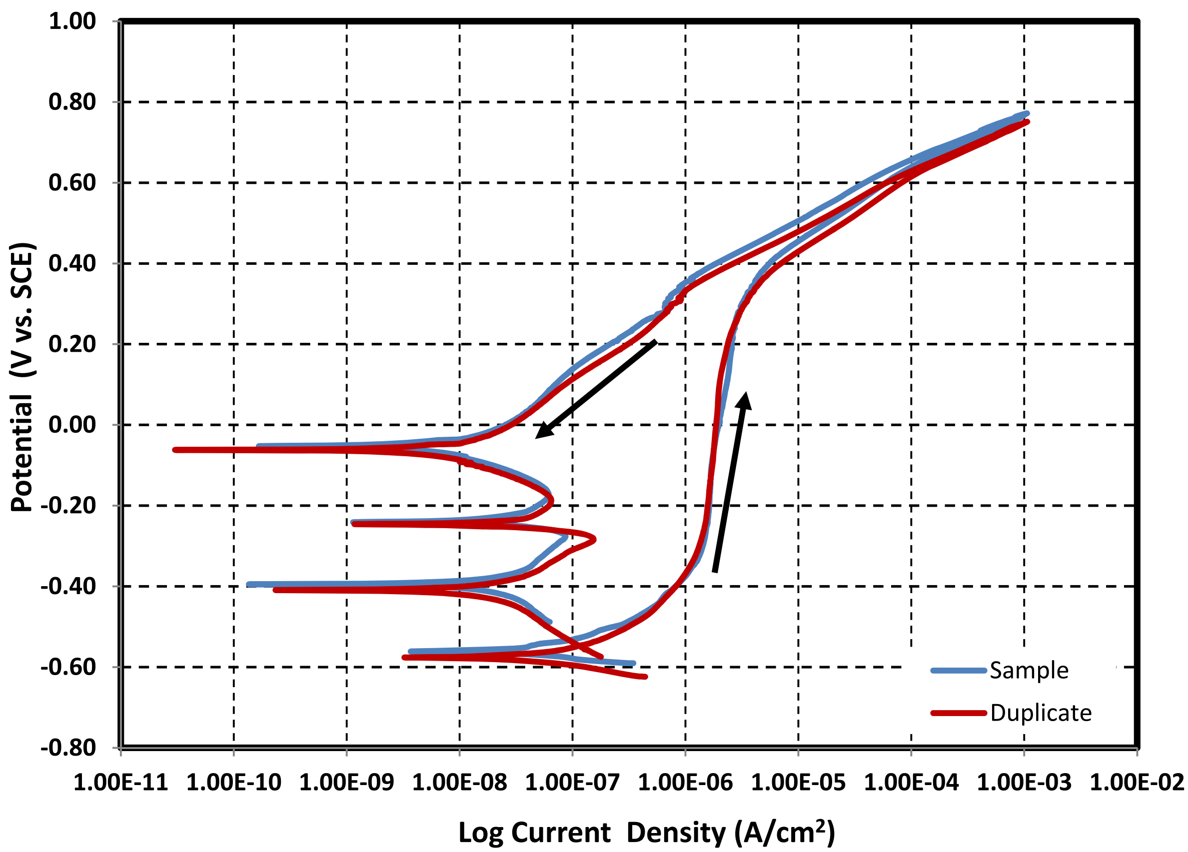
Composition of simulant for waste buffering-Test 6

Test 6

Temperature	40	°C
pH at temperature	11.39	
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

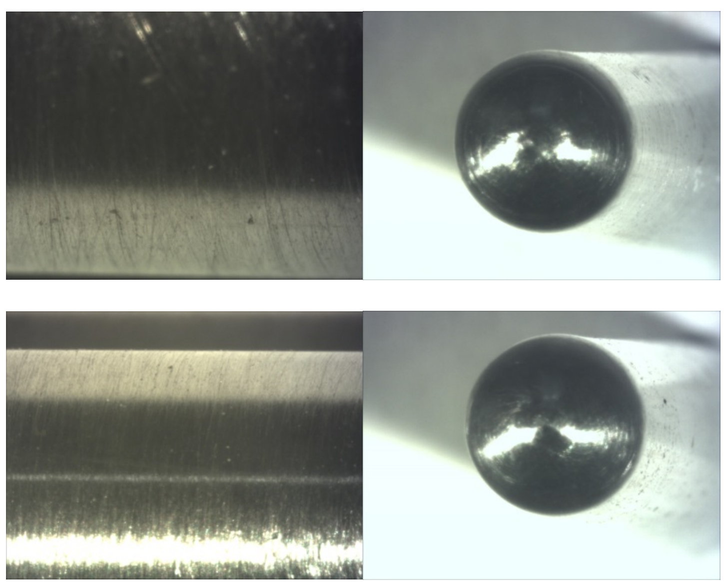
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 6

Test 6D



Shank (20X)

Nose (10X)

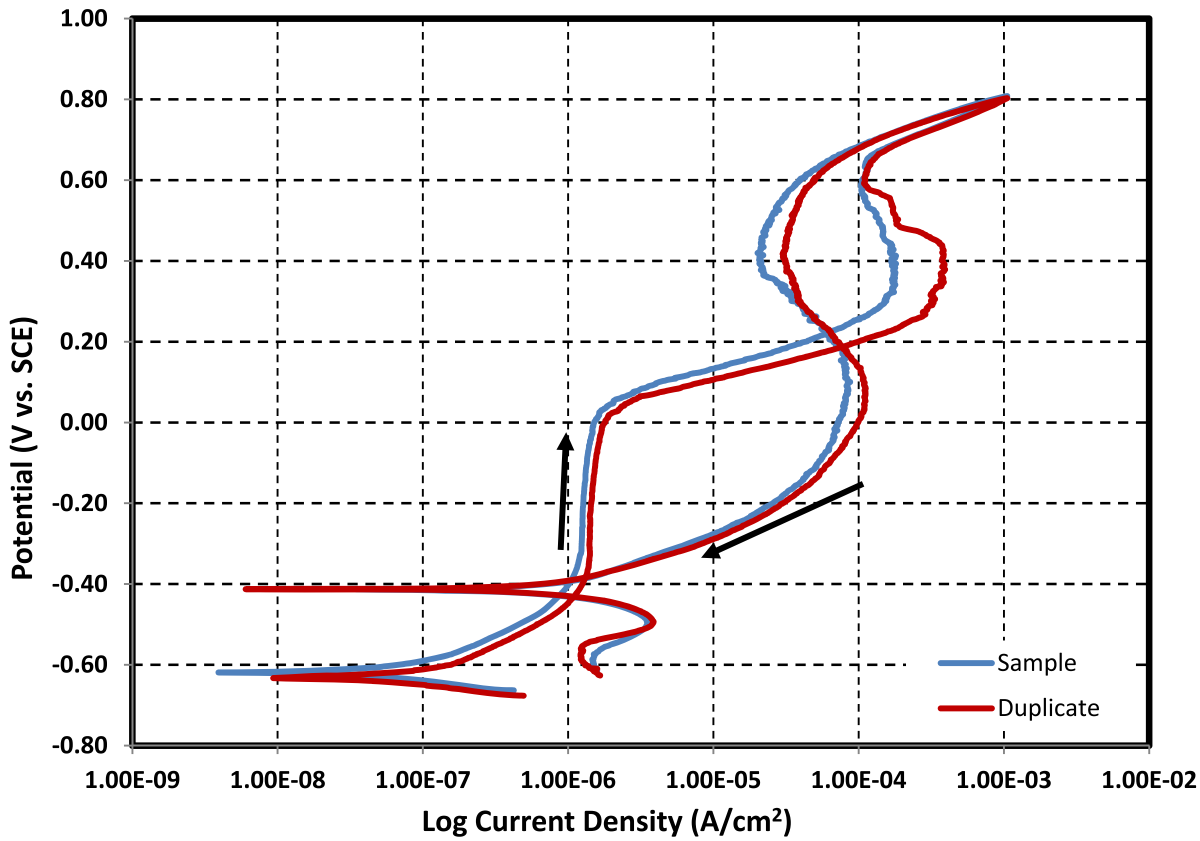
Composition of simulant for waste buffering-Test 13

Test 13

Temperature	40	°C
pH at temperature	11.34	
Volume	1.4	L

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	4.9040E+00	583.5760
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

Cyclic Potentiodynamic Polarization



No images taken. Large pits were observed in the sample and duplicate.

Simulants with Low Aluminum Nitrate Concentration (Modified simulant)

Summary of Tests

With pH adjustment and adjusting concentration of high nitrate solutions

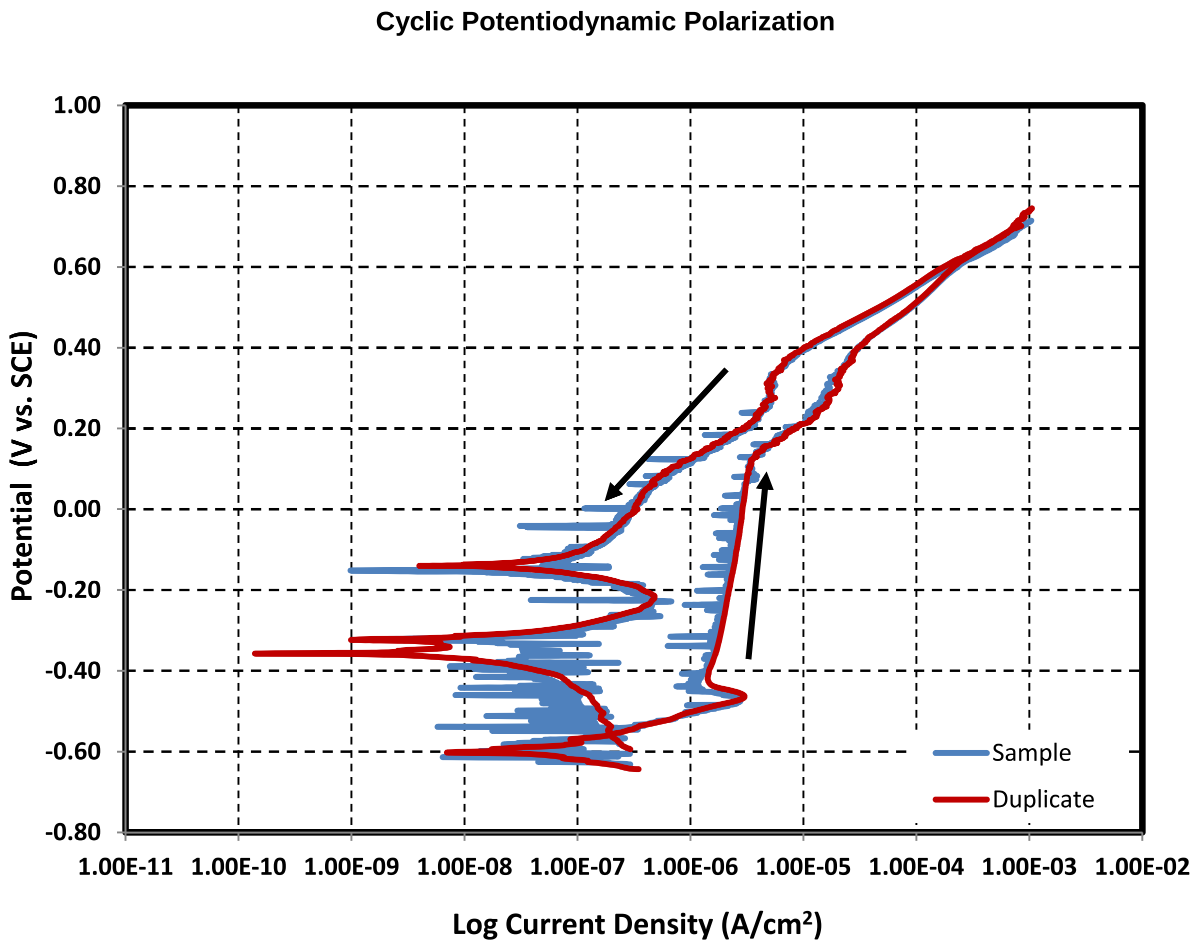
Test	Temperature (°C)	Nitrate (M)	Nitrite (M)	Hydroxide (M)	pH at 40°C	pH after adjusting at 40°C	Hysteresis	Pitting on Sample?
1	40	1.1	0.5	0.01	11.02	12.04	Negative	Minor
2	40	1.1	1	0.01	11.41	12.07	Negative	None
3	40	1.1	1.5	0.01	11.02	12.01	Negative	None
4	40	1.1	0.5	0.05	11.91	12.74	Negative	Minor
5	40	1.1	1	0.05	12.09	12.76	Negative	None
6	40	1.1	1.5	0.05	12.06	12.74	Negative	None
7	40	3	0.5	0.01	11.34	12.01	Mixed	Major
13	40	5.004	0.5	0.01	11.69	12.01	Positive	Major
14	40	4.252	1	0.01	11.33	12.08	Negative	Minor
15	40	4.089	1.5	0.01	11.25	12.05	Negative	None
16	40	5.004	0.5	0.05	11.57	12.71	Mixed	Minor
17	40	4.252	1	0.05	11.32	12.72	Negative	None
18	40	4.089	1.5	0.05	11.46	12.71	Negative	None

Composition of simulant for waste buffering-Test 1

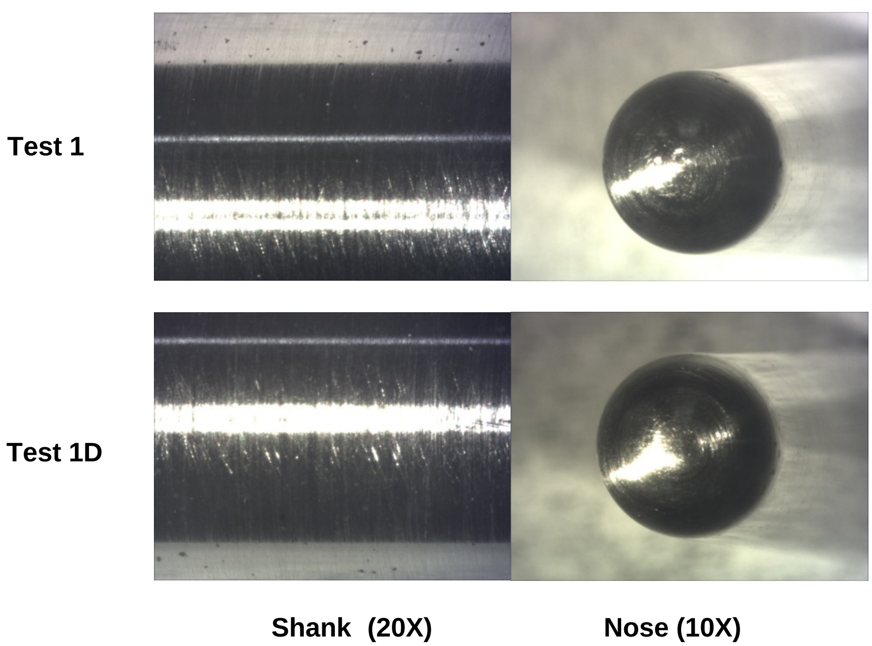
Test 1

Temperature	40	°C		
pH at temperature	11.02	pH adjusted	12.04	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000



Images of bullet samples after electrochemical tests



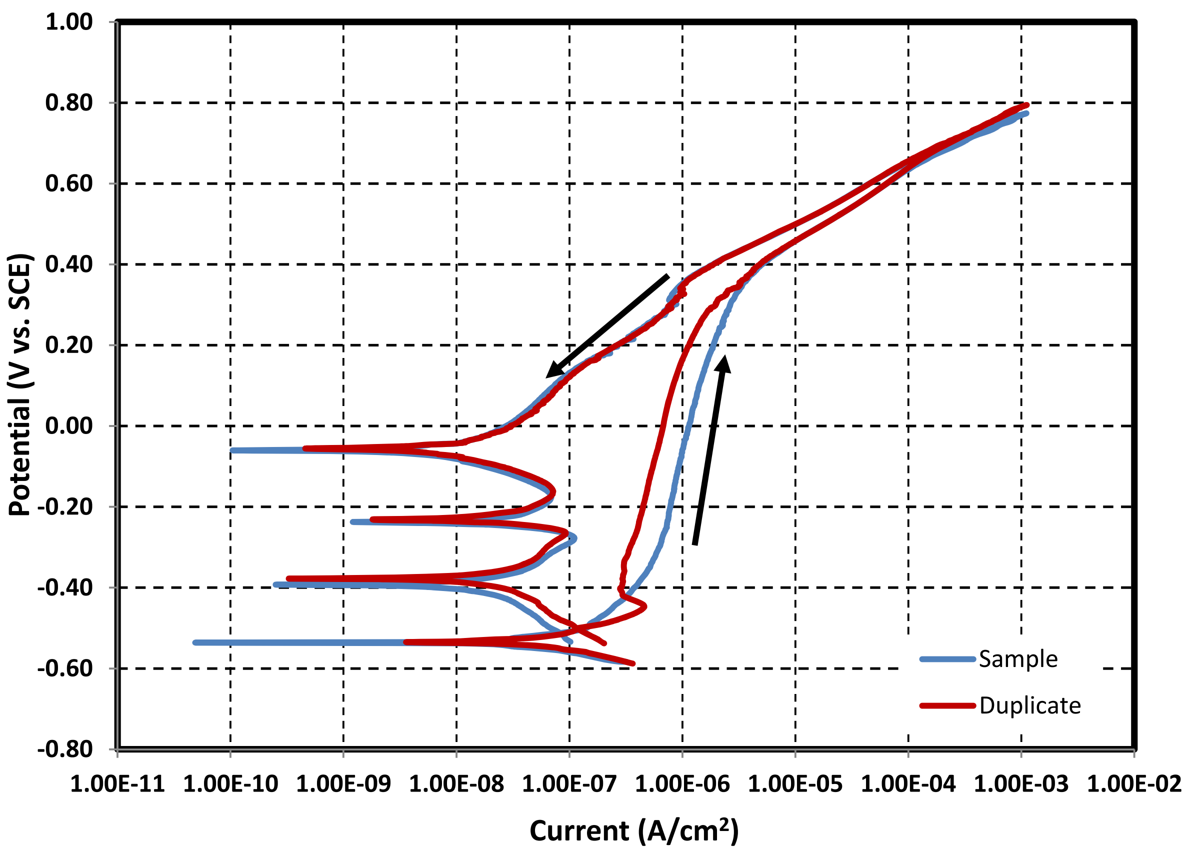
Composition of simulant for waste buffering-Test 2

Test 2

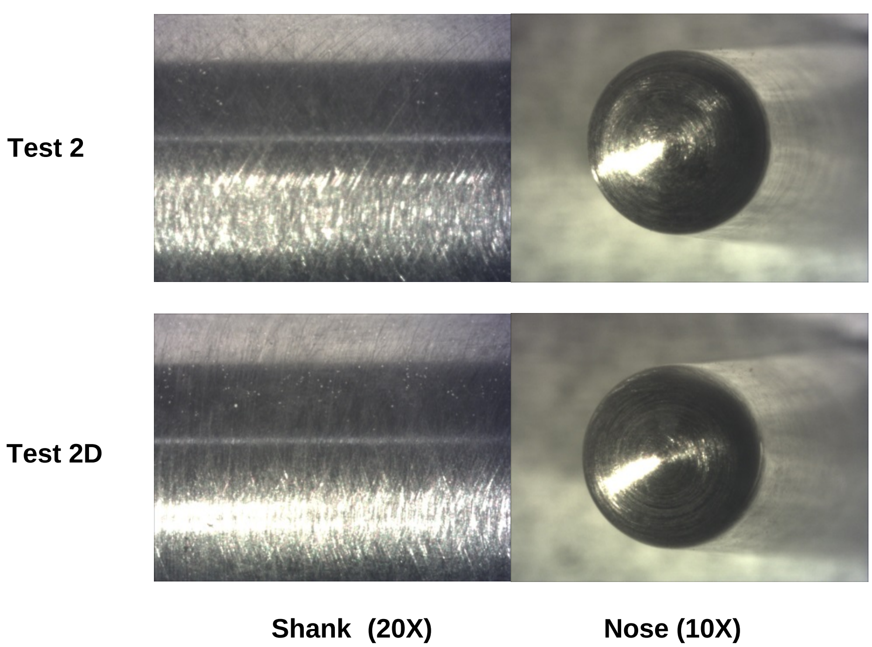
Temperature	40	°C		
pH at temperature	11.41	pH adjusted	12.07	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



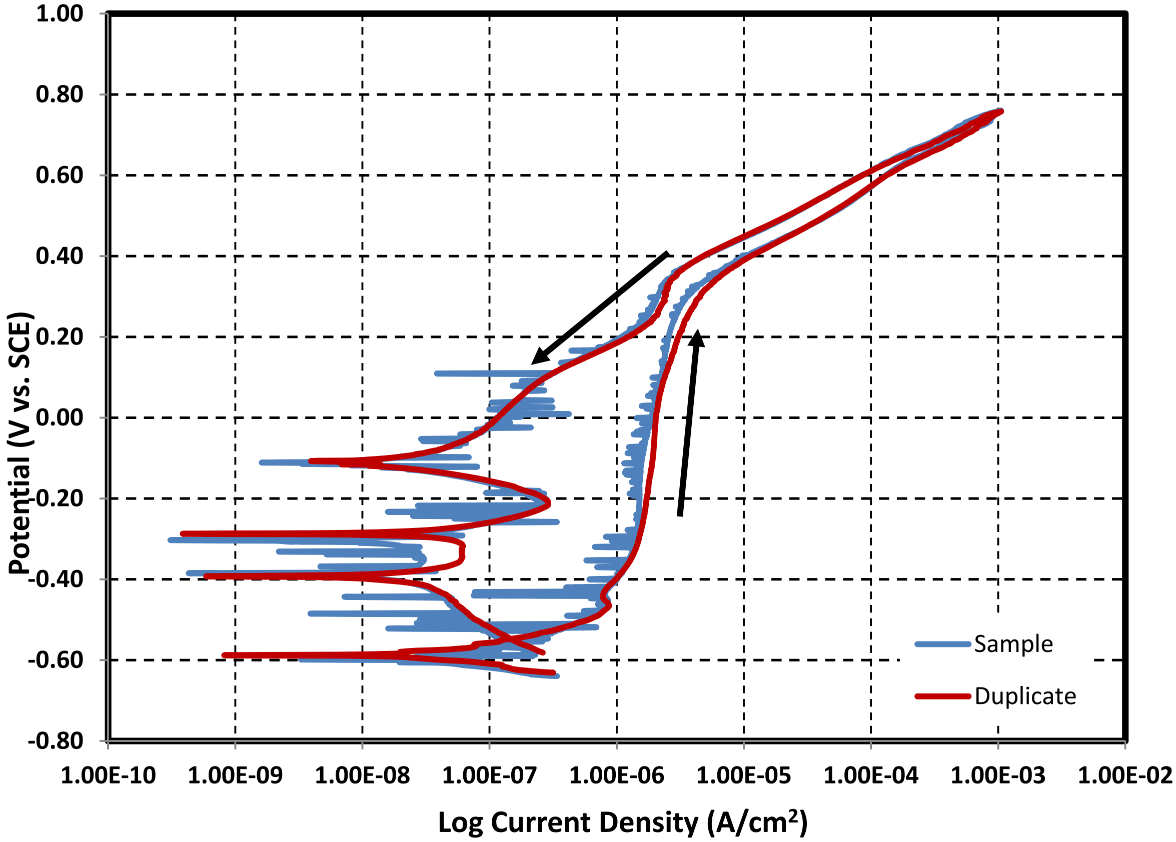
Composition of simulant for waste buffering-Test 3

Test 3

Temperature	40	°C		
pH at temperature	11.02	pH adjusted	12.01	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

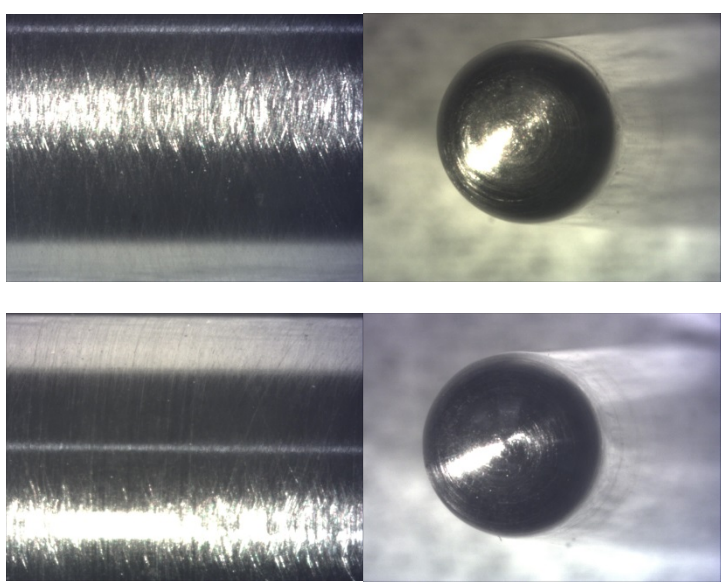
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 3

Test 3D



Shank (20X) Nose (10X)

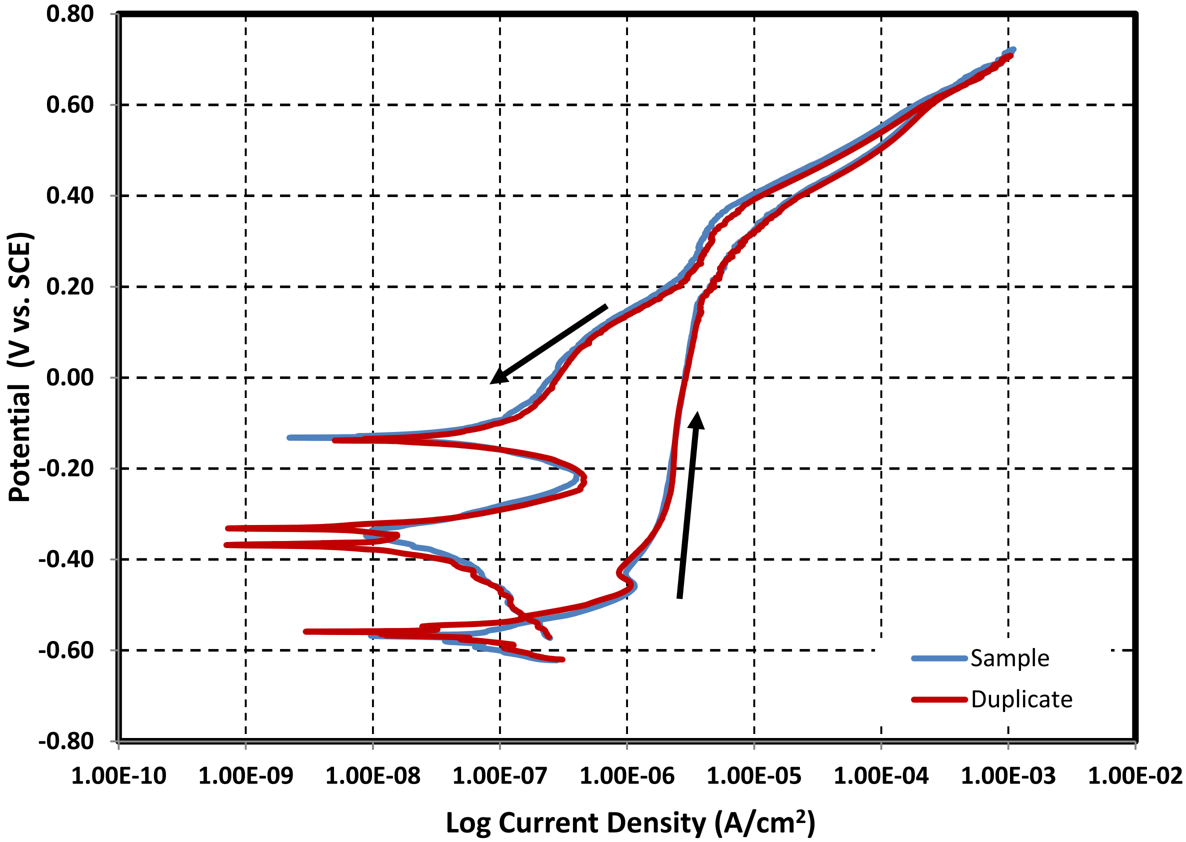
Composition of simulant for waste buffering-Test 4

Test 4

Temperature	40	°C		
pH at temperature	11.91	pH adjusted	12.74	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

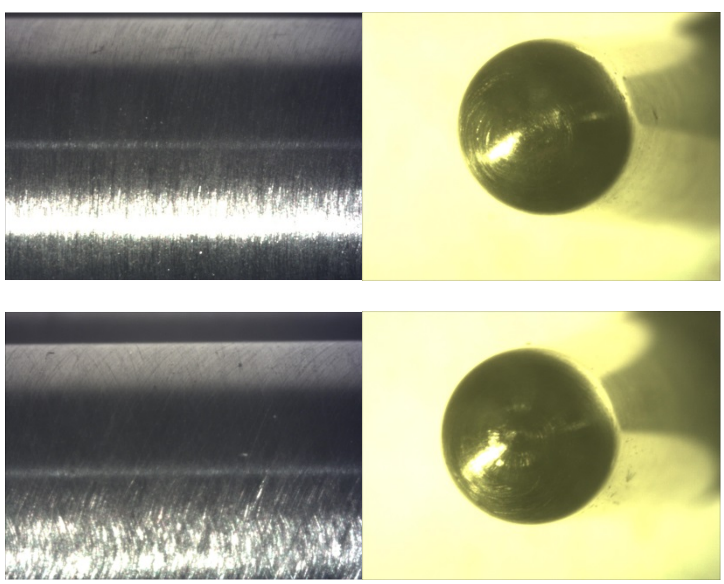
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 4

Test 4D



Shank (20X) Nose (10X)

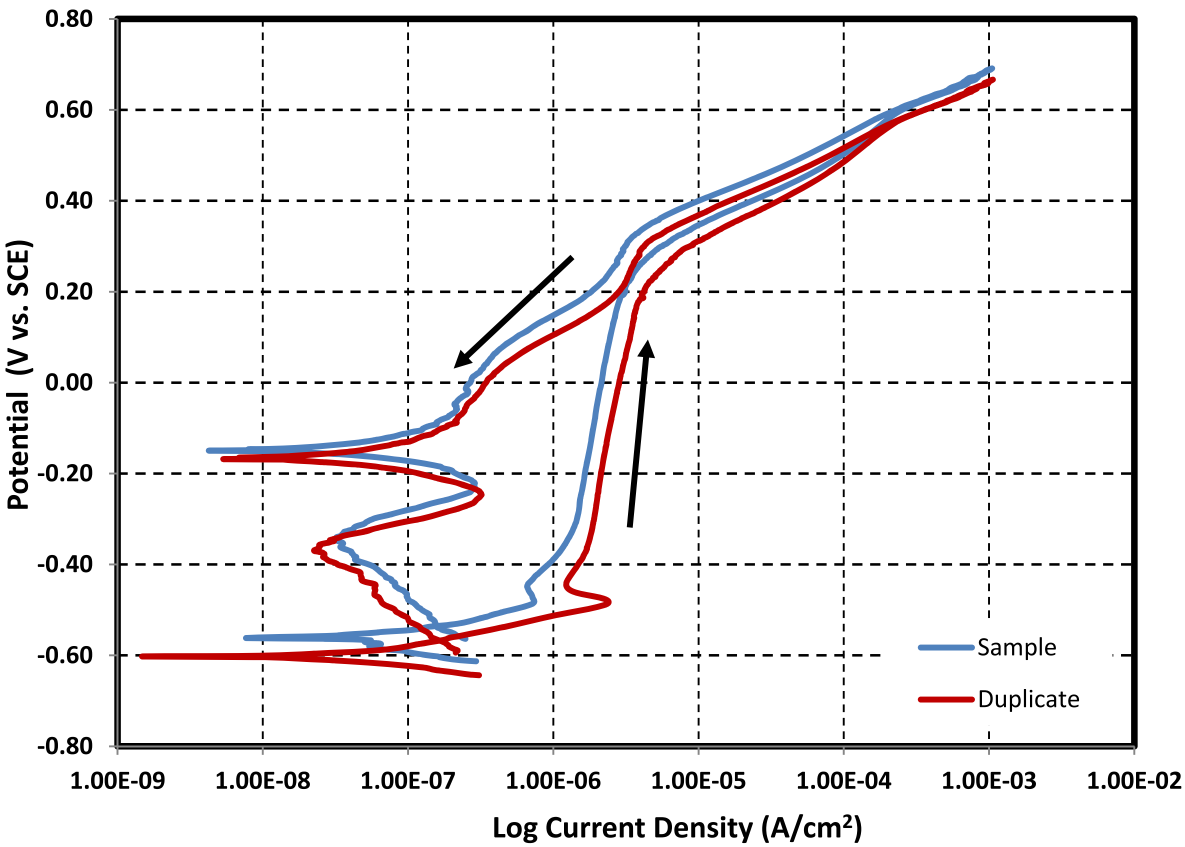
Composition of simulant for waste buffering-Test 5

Test 5

Temperature	40	°C		
pH at temperature	12.09	pH adjusted	12.76	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

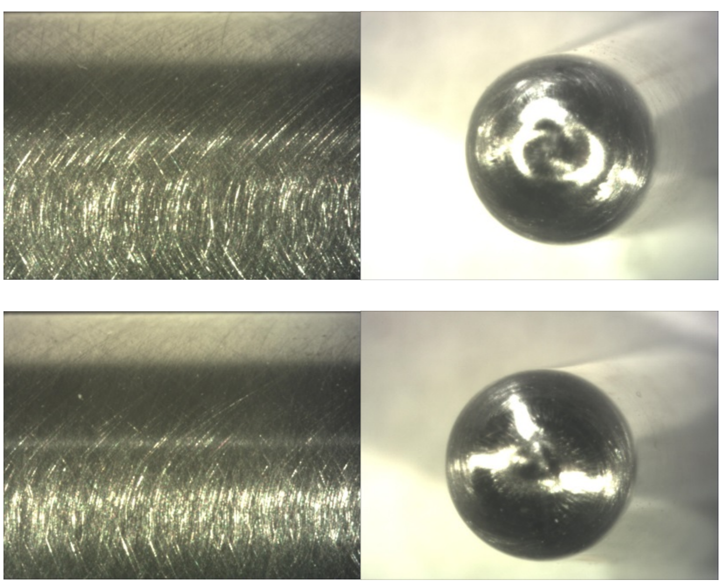
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 5

Test 5D



Shank (20X) Nose (10X)

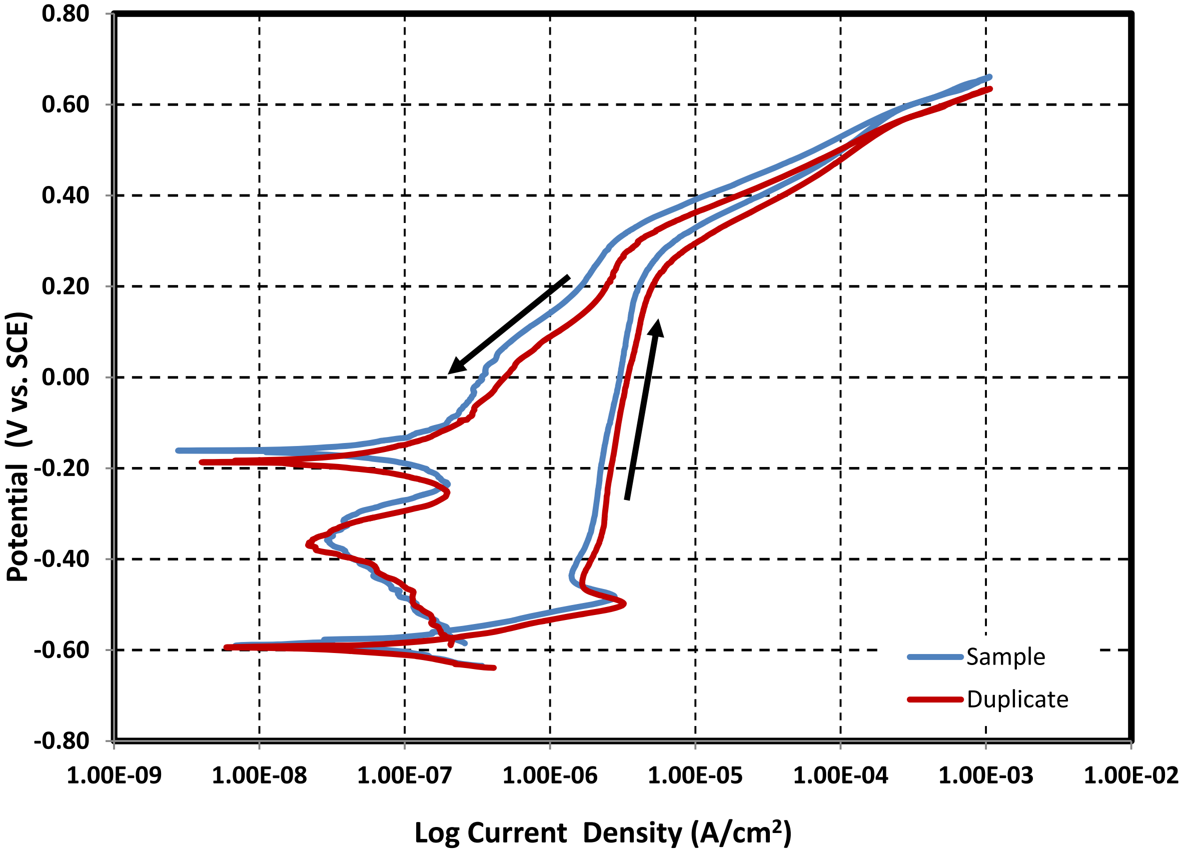
Composition of simulant for waste buffering-Test 6

Test 6

Temperature	40	°C		
pH at temperature	12.06	pH adjusted	12.74	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	1.0000E+00	119.0000
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

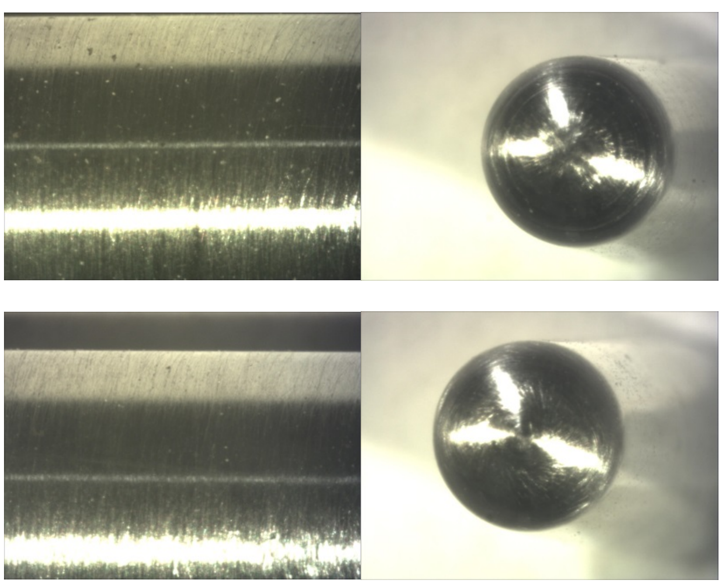
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 6

Test 6D



Shank (20X) Nose (10X)

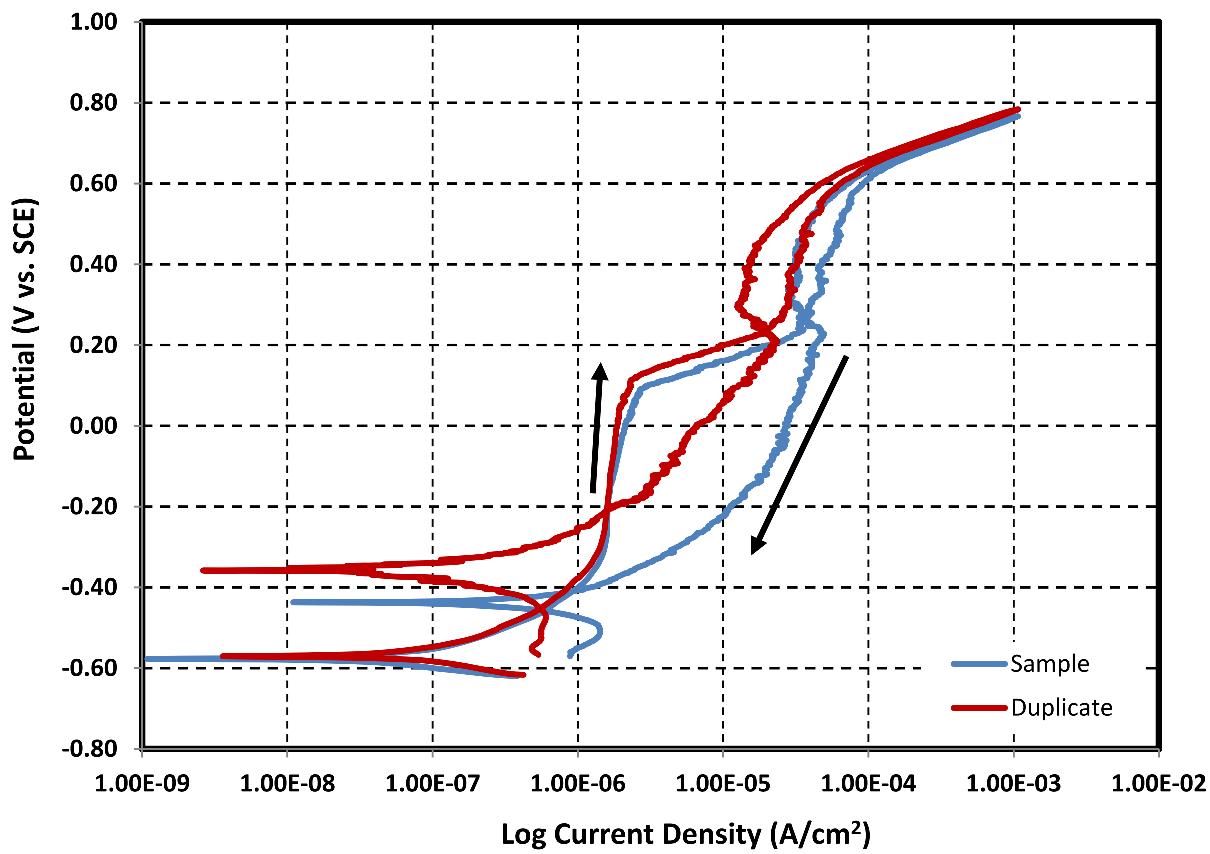
Composition of simulant for waste buffering-Test 7

Test 12

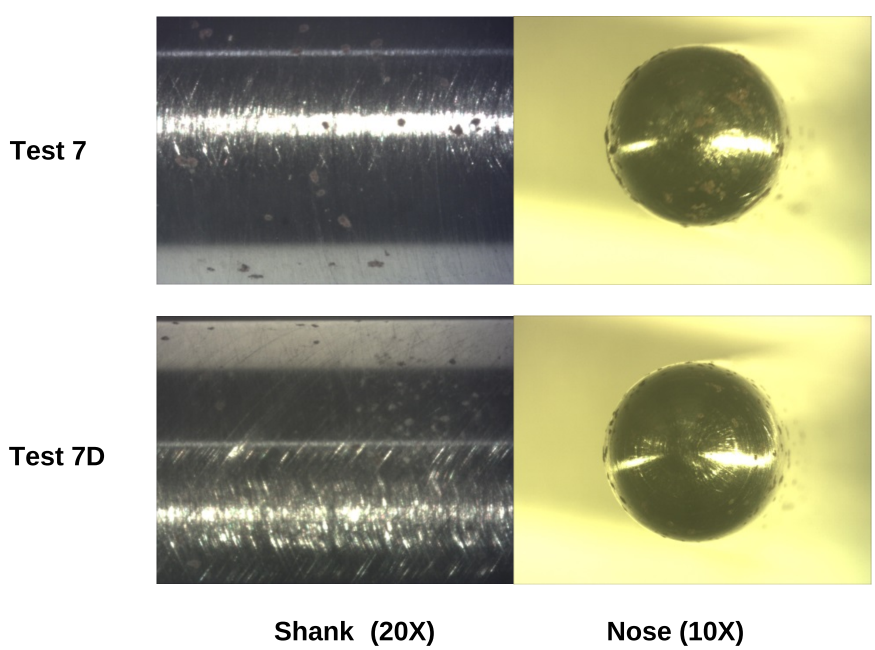
Temperature	40	°C		
pH at temperature	11.34	pH adjusted	12.01	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	Na(CHO2)	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	2.9000E+00	345.1000
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



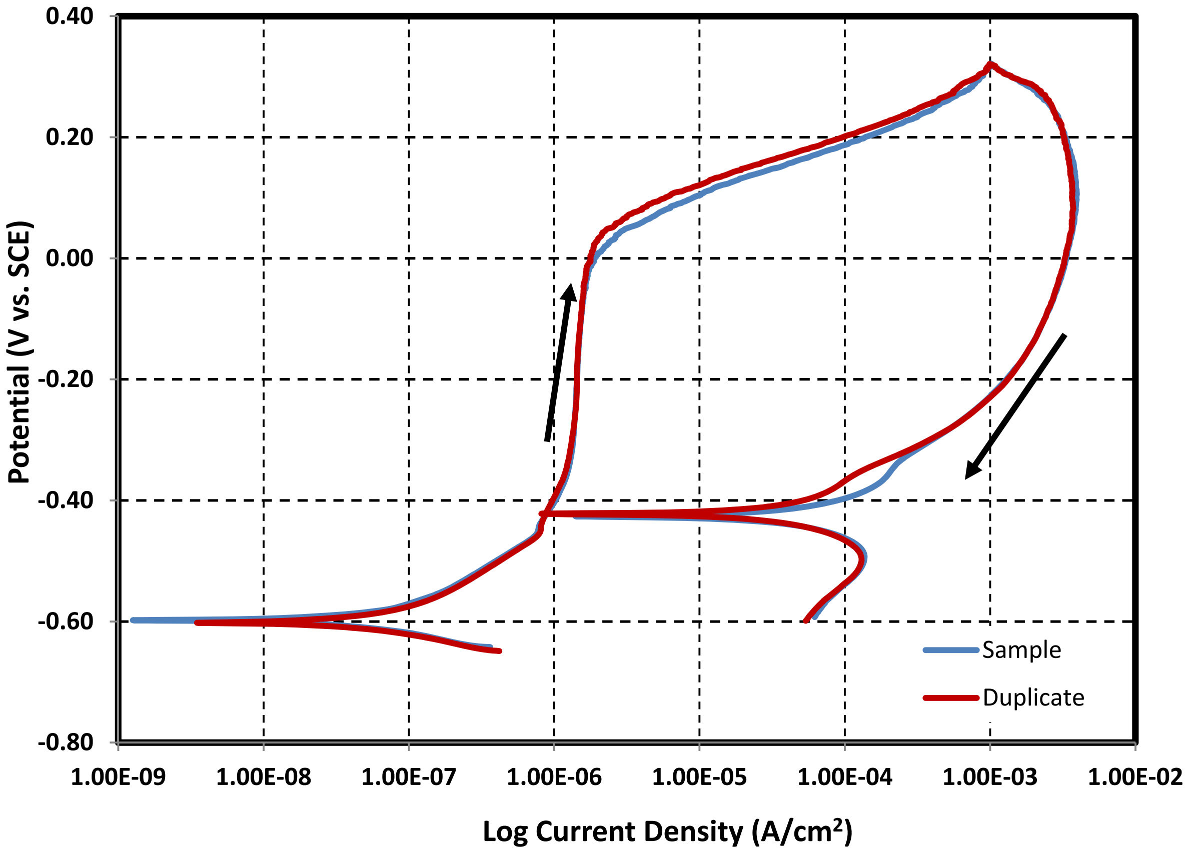
Composition of simulant for waste buffering-Test 13

Test 13

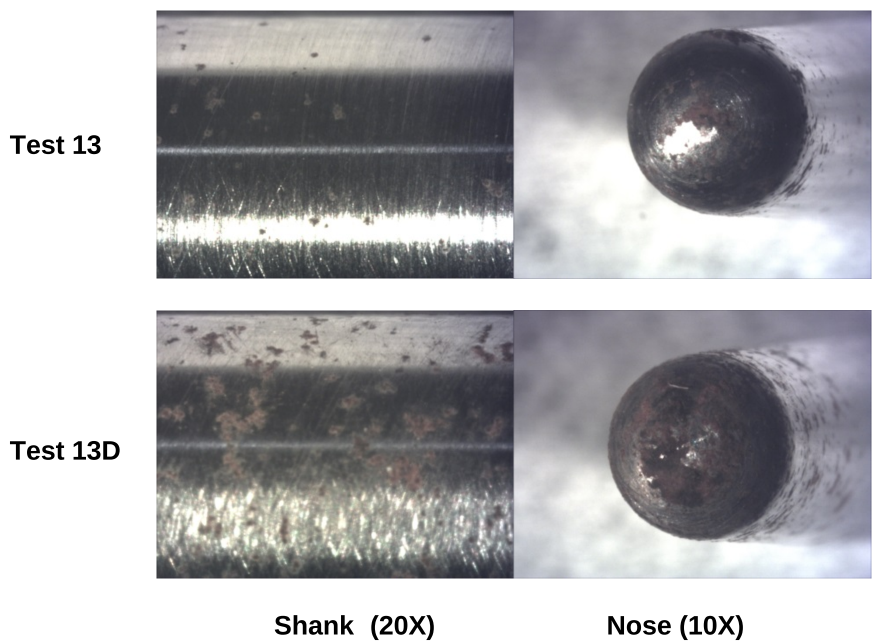
Temperature	40	°C		
pH at temperature	11.69	pH adjusted	12.01	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	4.9040E+00	583.5760
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



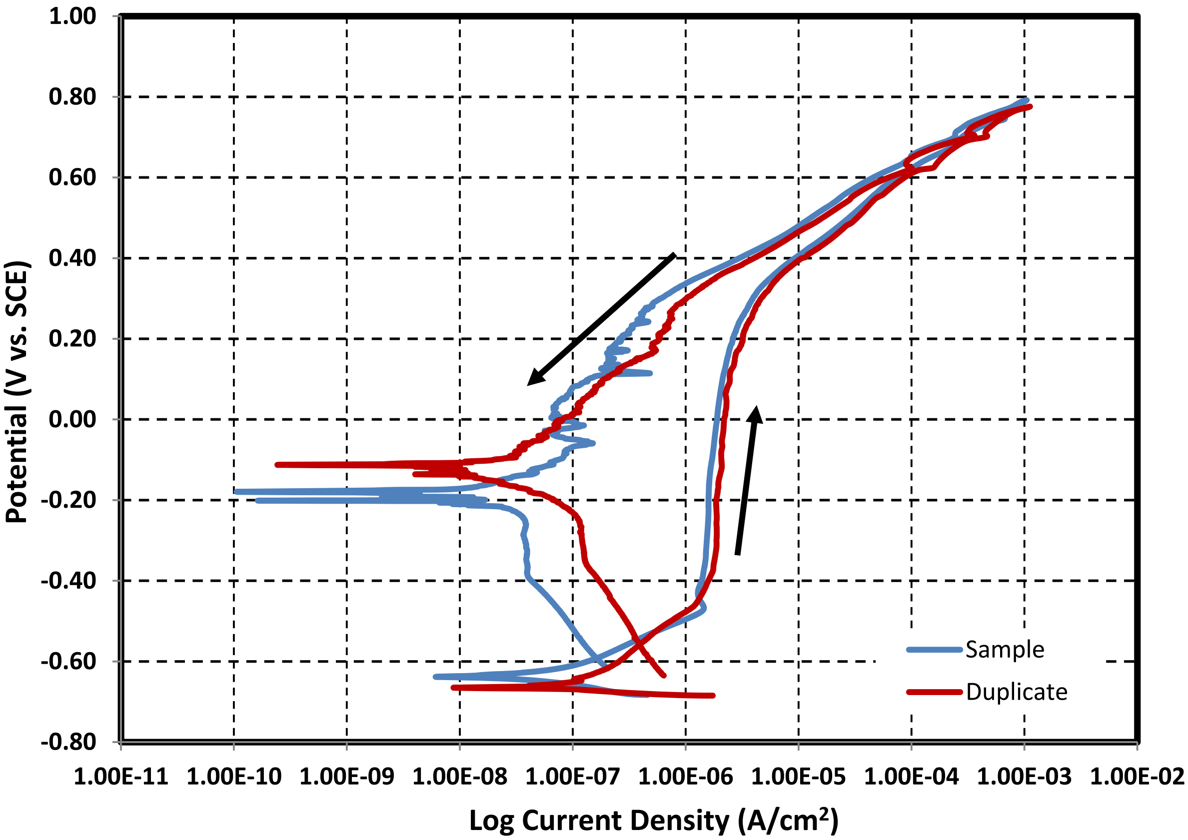
Composition of simulant for waste buffering-Test 14

Test 14

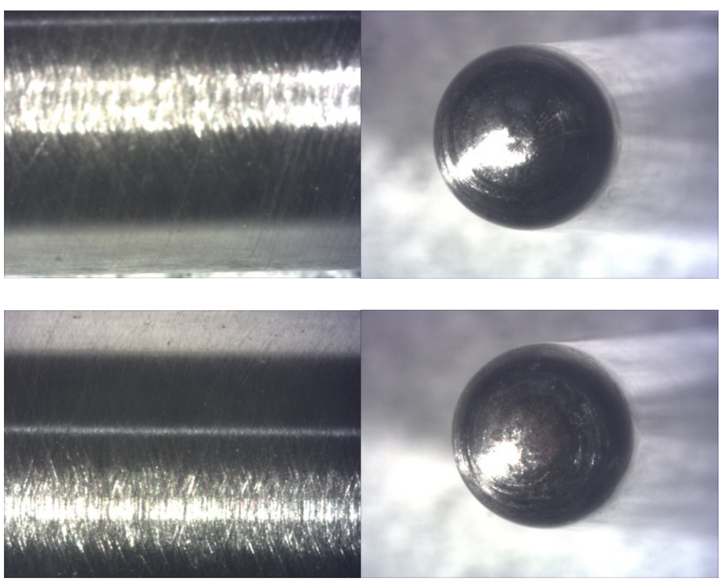
Temperature	40	°C		
pH at temperature	11.33	pH adjusted	12.08	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	4.1520E+00	494.0880
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



Test 14

Test 14D

Shank (20X) **Nose (10X)**

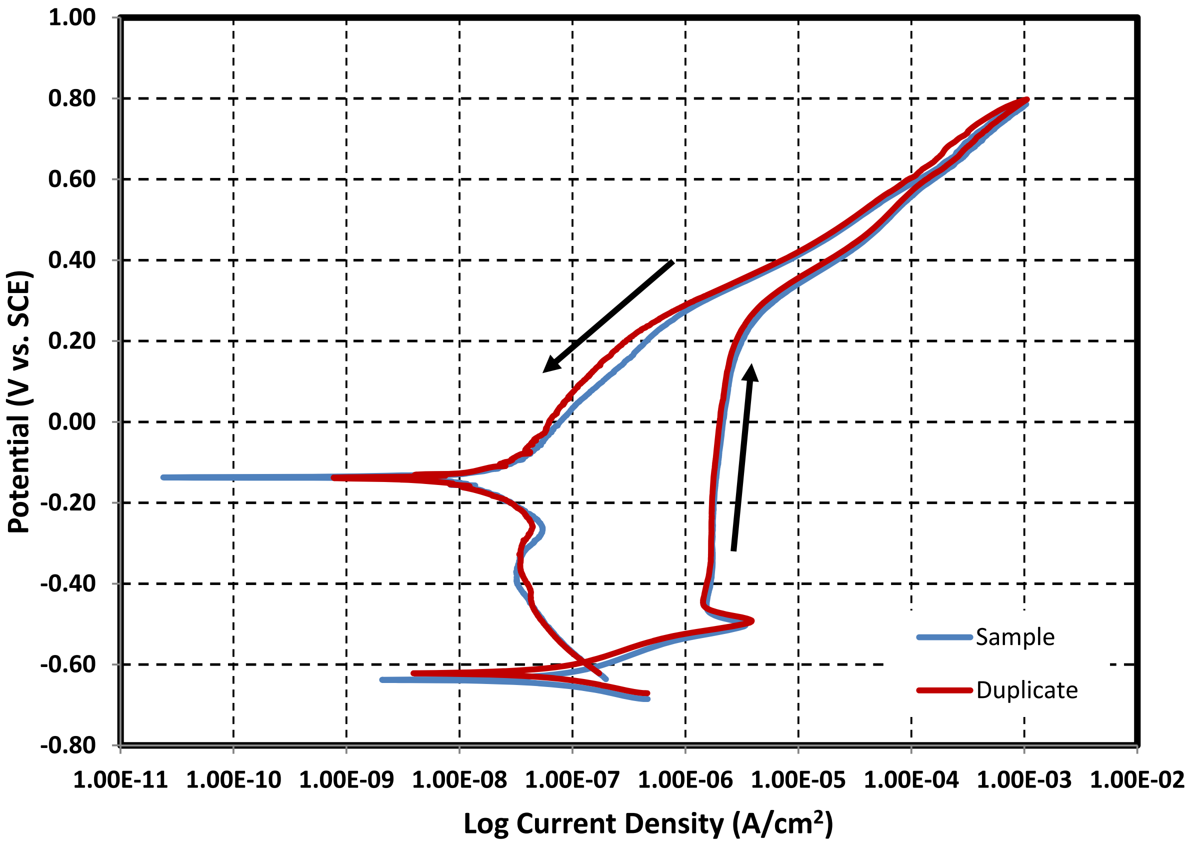
Composition of simulant for waste buffering-Test 15

Test 15

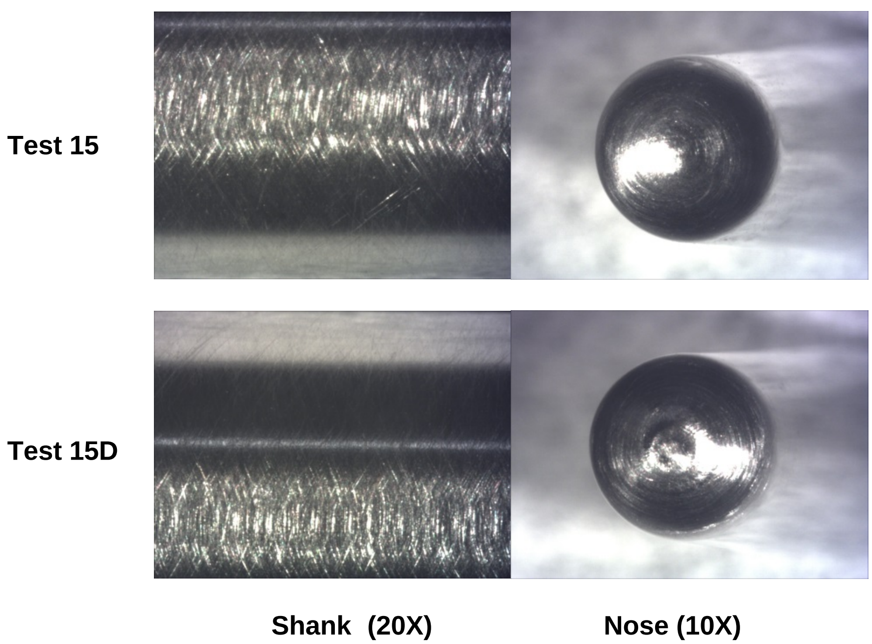
Temperature	40	°C		
pH at temperature	11.25	pH adjusted	12.05	(12.00)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.3400E-01	52.3040
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	3.9890E+00	474.6910
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



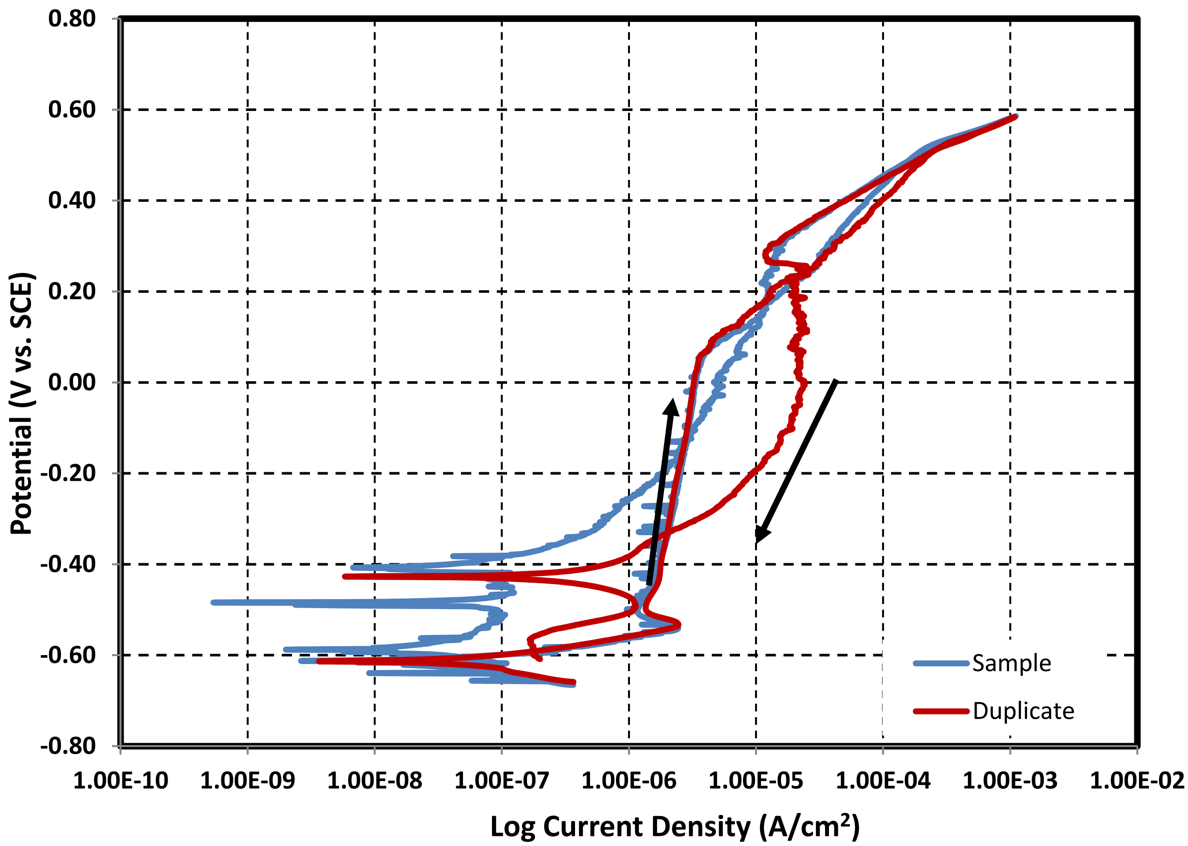
Composition of simulant for waste buffering-Test 16

Test 16

Temperature	40	°C		
pH at temperature	11.57	pH adjusted	12.71	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	NaCl	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	NaOH	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	4.9040E+00	583.5760
Sodium nitrite	$NaNO_2$	69.0000	5.0000E-01	48.3000

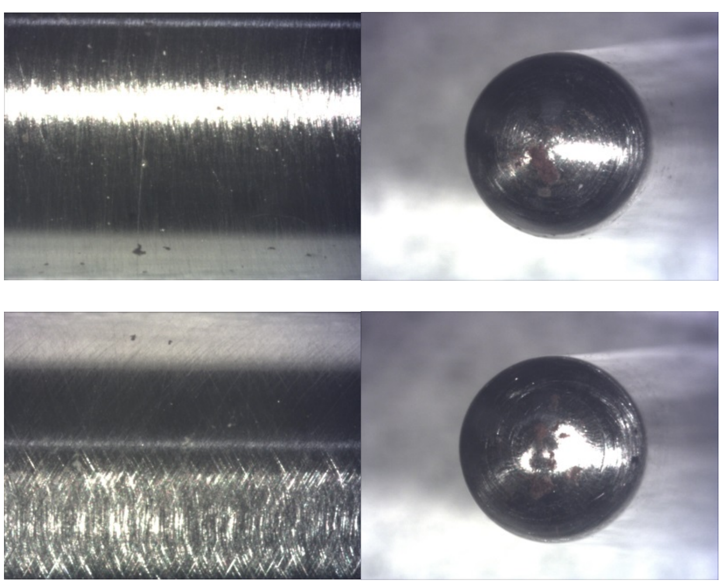
Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests

Test 16

Test 16D



Shank (20X) Nose (10X)

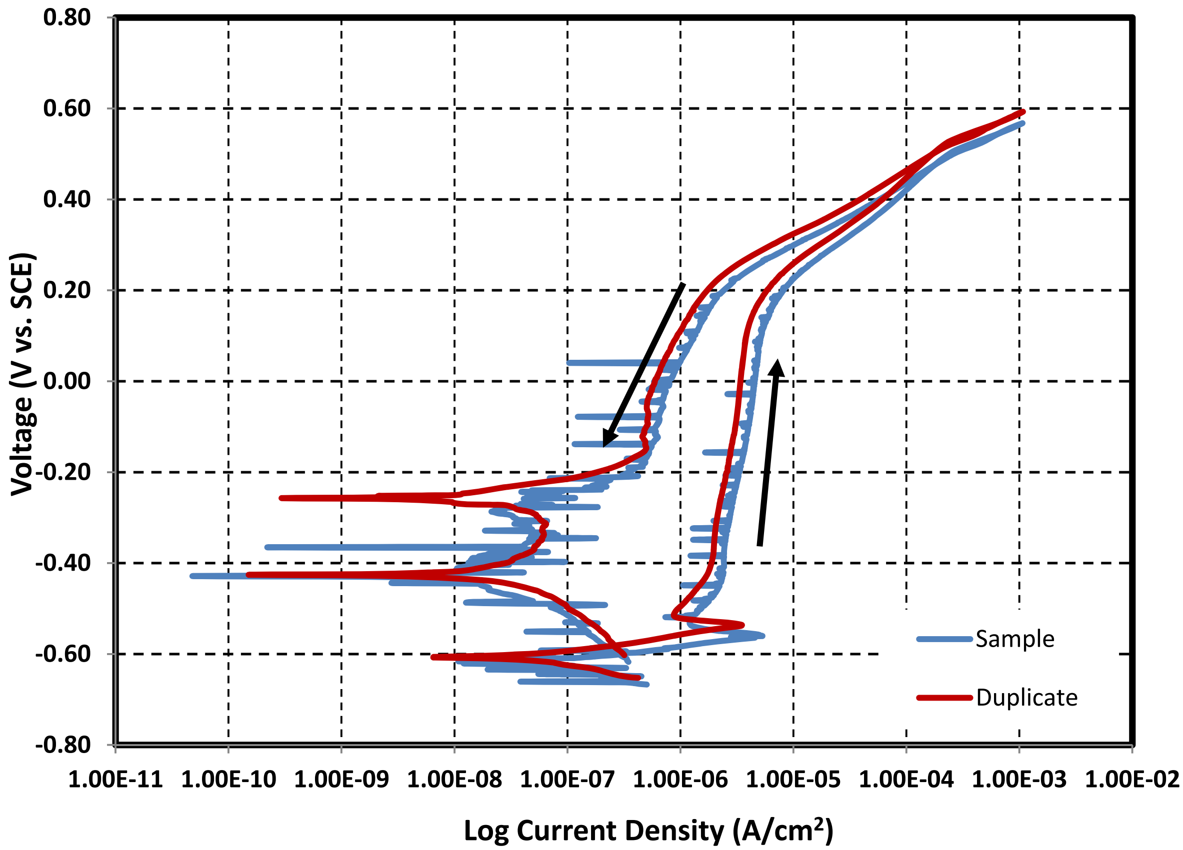
Composition of simulant for waste buffering-Test 17

Test 17

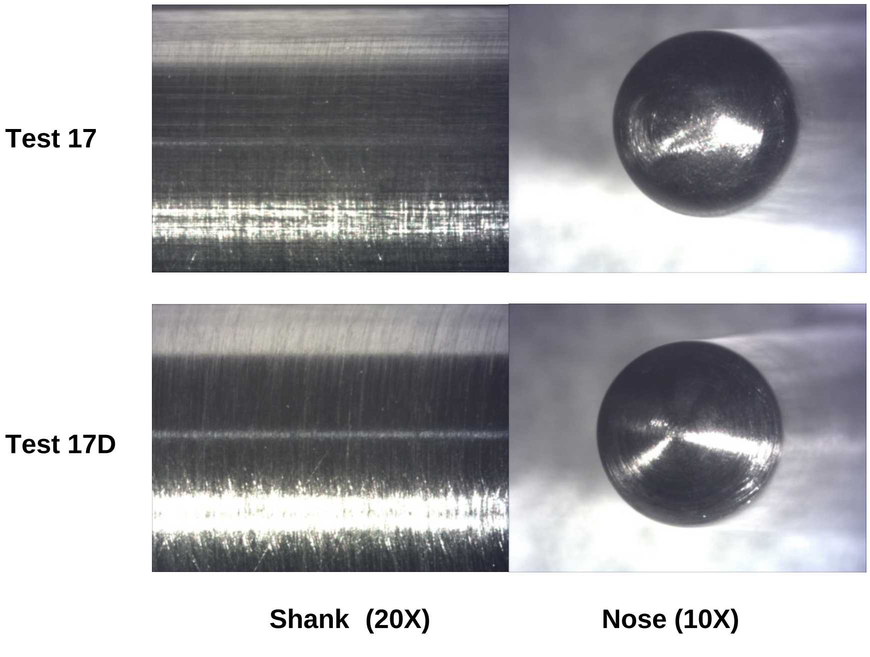
Temperature	40	°C		
pH at temperature	11.32	pH adjusted	12.72	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	4.1520E+00	494.0880
Sodium nitrite	$NaNO_2$	69.0000	1.0000E+00	96.6000

Cyclic Potentiodynamic Polarization



Images of bullet samples after electrochemical tests



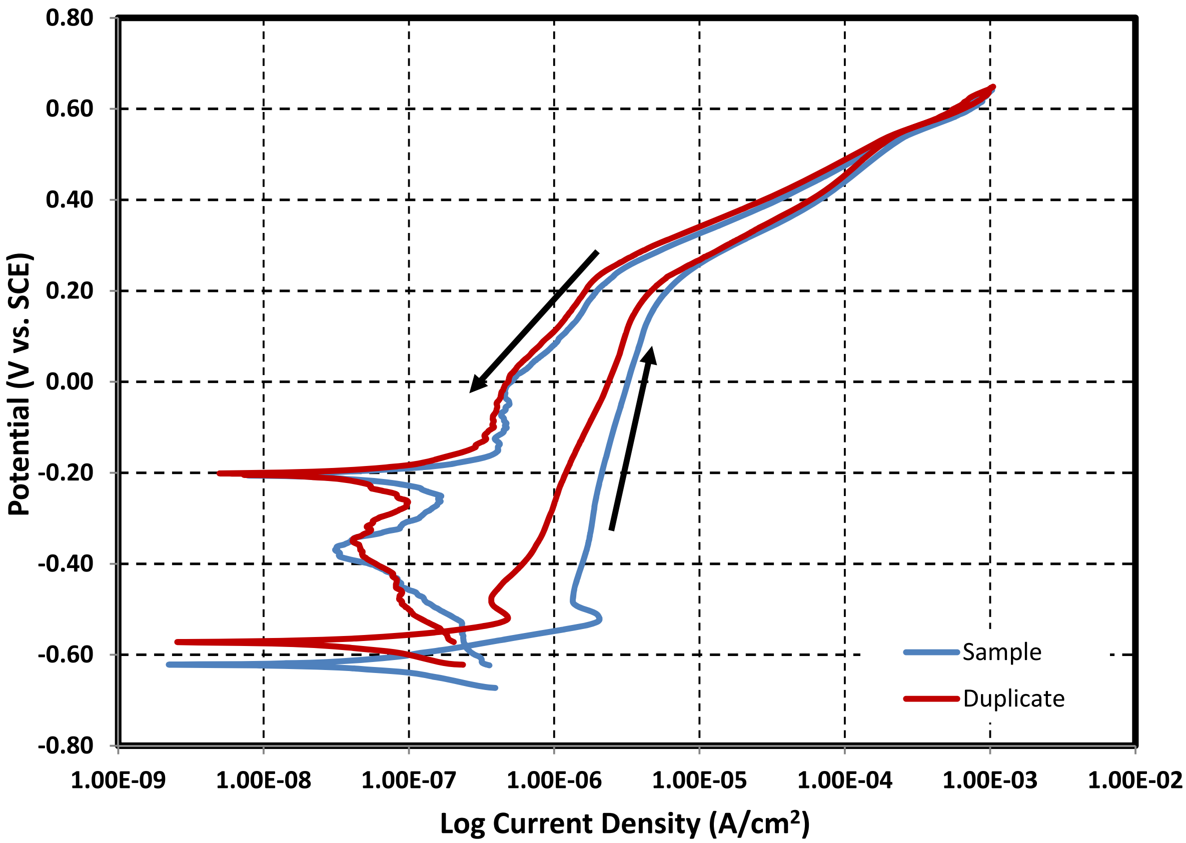
Composition of simulant for waste buffering-Test 18

Test 18

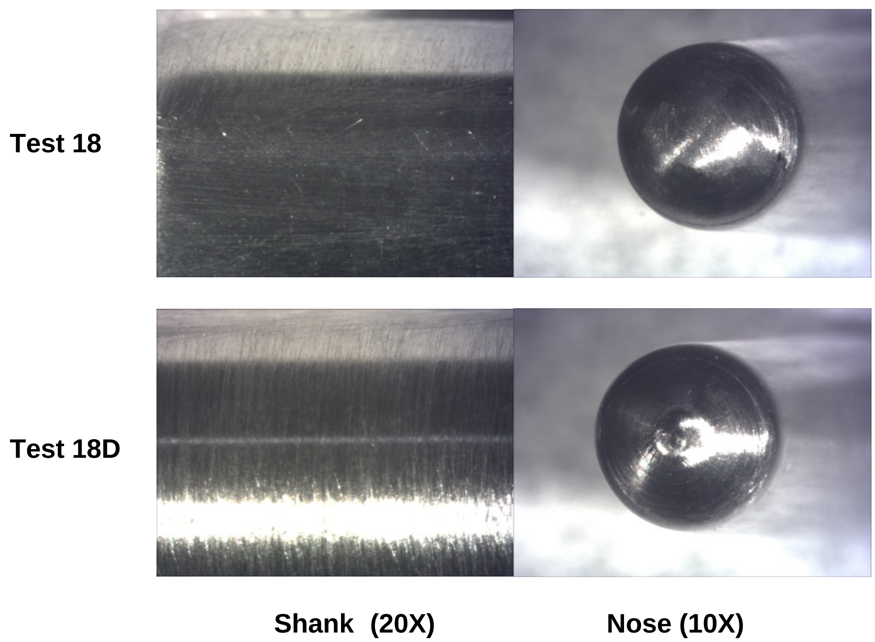
Temperature	40	°C		
pH at temperature	11.46	pH adjusted	12.71	(12.70)
Volume	1.4	L		

Simulant Source	Formula	Molecular Weight (g/mol)	Concentration (M)	weight required (g)
Aluminum nitrate, 9-hydrate	$Al(NO_3)_3.9H_2O$	375.0000	5.0000E-03	2.6250
Ammonium Chloride	NH_4Cl	55.4920	4.9800E-03	0.3869
Cadmium nitrate, 4-hydrate	$Cd(NO_3)_2.4H_2O$	308.0000	5.5300E-04	0.2385
Calcium nitrate, 4-hydrate	$Ca(NO_3)_2.4H_2O$	236.0000	1.0000E-02	3.3040
Cupric nitrate, 2.5 hydrate	$Cu(NO_3)_2.2.5H_2O$	233.0000	3.7500E-04	0.1223
Ferric nitrate, 9-hydrate	$Fe(NO_3)_3.9H_2O$	404.0000	5.7500E-04	0.3252
Lanthanum nitrate, 6-hydrate	$La(NO_3)_3.6H_2O$	433.0000	8.6400E-05	0.0524
Lead nitrate	$Pb(NO_3)_2$	331.0000	6.5600E-04	0.3040
Manganous chloride, 4-hydrate	$MnCl_2.4H_2O$	198.0000	3.2400E-04	0.0898
Nickel nitrate, 6-hydrate	$Ni(NO_3)_2.6H_2O$	291.0000	6.7500E-03	2.7500
Potassium nitrate	$K(NO_3)$	101.0000	4.6400E-02	6.5610
Sodium chloride	$NaCl$	58.4000	1.0600E-01	8.6666
Sodium sulfate	Na_2SO_4	142.0000	1.2800E-01	25.4464
Sodium phosphate, 12-hydrate	$Na_3PO_4.12H_2O$	380.0000	5.1400E-02	27.3448
Glycolic acid	$C_2H_4O_3$	76.1000	1.6100E-01	17.1529
Citric acid, 1-hydrate	$C_6H_8O_7.H_2O$	210.0000	1.1141E-01	32.7540
Disodium EDTA	$Na_2C_{10}H_{14}O_8.2H_2O$	372.0000	4.8108E-02	25.0546
HEDTA	$C_{10}H_{18}N_2O_7$	278.0000	1.8990E-02	7.3909
Nitrilotriacetic Acid	$C_6H_9NO_6$	191.0000	7.5960E-03	2.0312
Iminodiacetic Acid	$C_4H_7NO_2$	133.0000	1.1267E-01	20.9799
Sodium gluconate	$C_6H_{11}O_7Na$	218.0000	2.5320E-02	7.7277
Sodium hydroxide	$NaOH$	40.0000	9.7400E-01	54.5440
Sodium acetate, 3-hydrate	$Na(C_2H_3O_2).3H_2O$	136.0000	2.0800E-02	3.9603
Sodium formate	$Na(CHO_2)$	68.0000	2.3300E-01	22.1816
Sodium carbonate	Na_2CO_3	106.0000	1.1200E+00	166.2080
Sodium nitrate	$NaNO_3$	85.0000	3.9890E+00	474.6910
Sodium nitrite	$NaNO_2$	69.0000	1.5000E+00	144.9000

Cyclic Potentiodynamic Polarization



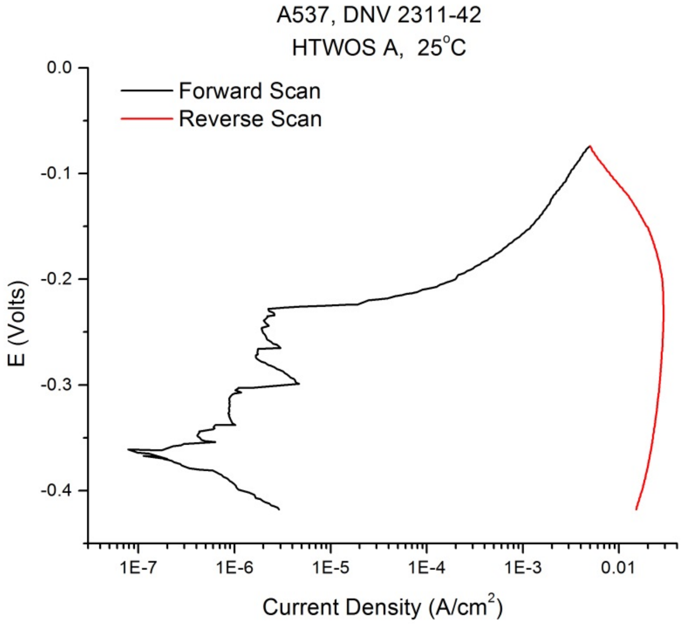
Images of bullet samples after electrochemical tests

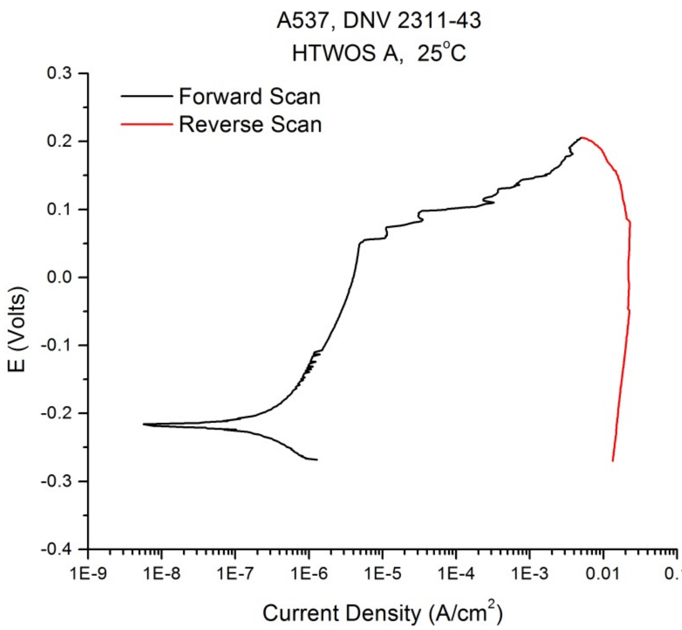


Appendix H

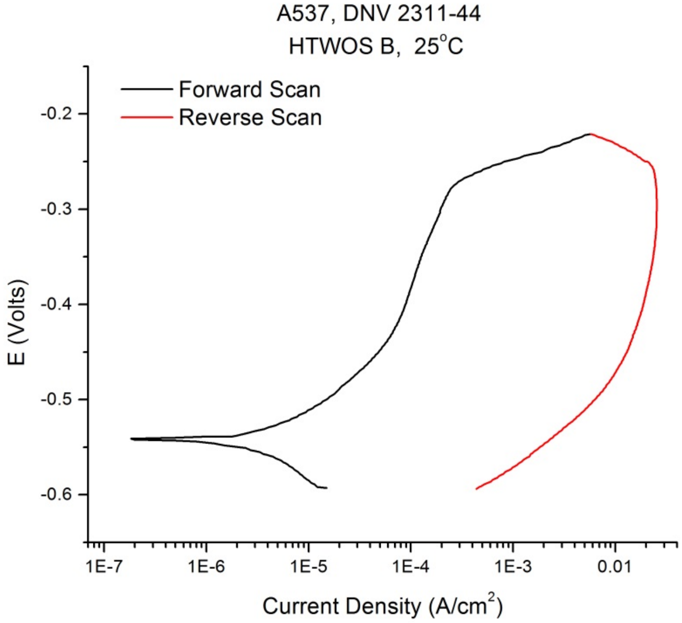
Electrochemical Results for Material Selection (Task 5)

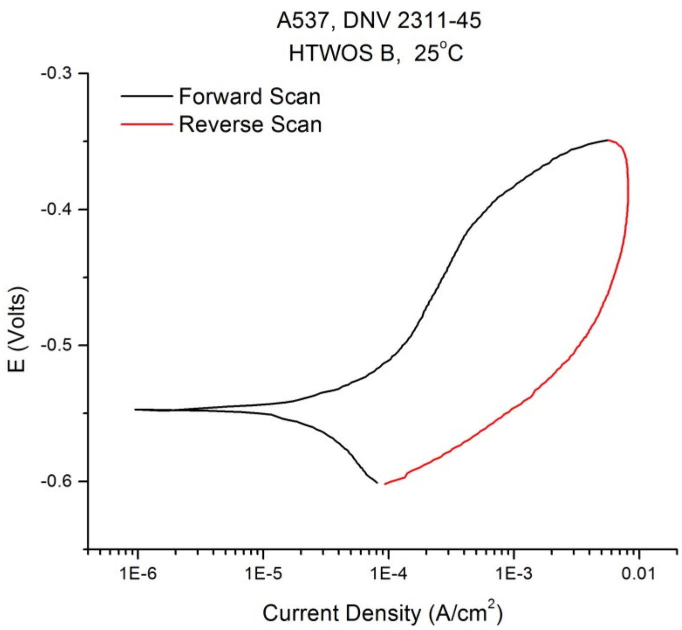
Cyclic Potentiodynamic Polarization Test 2311, HTWOS A



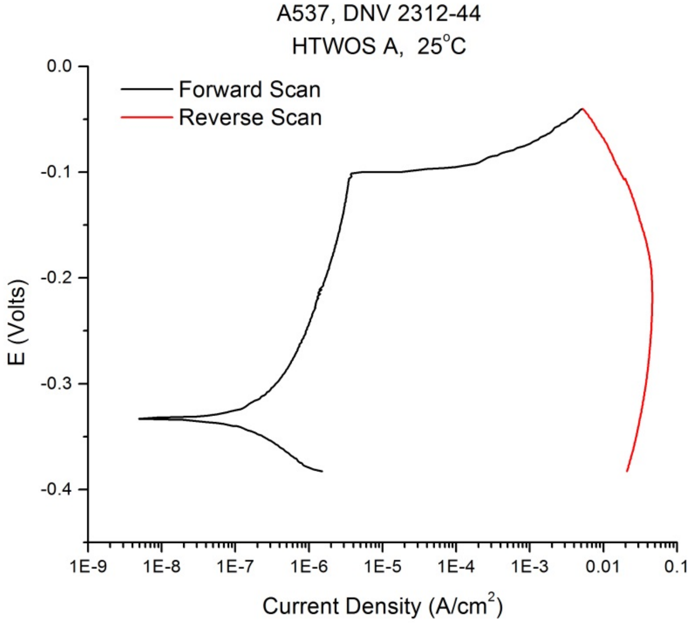


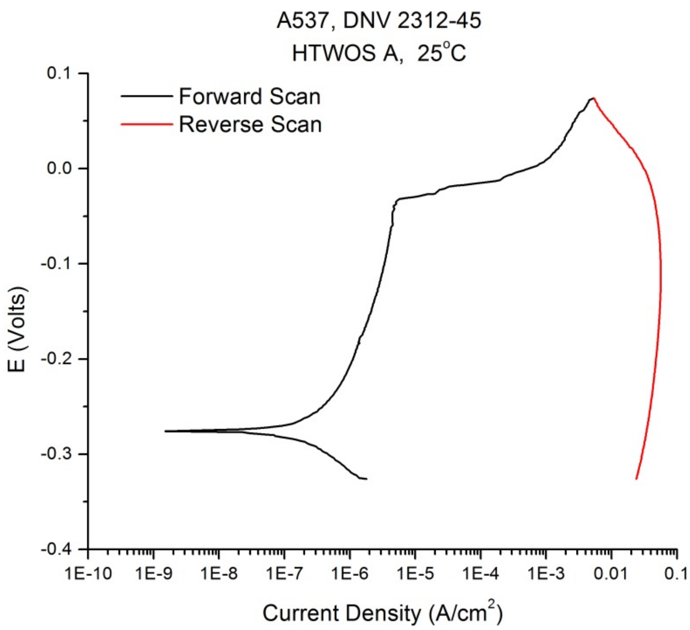
Cyclic Potentiodynamic Polarization Test 2311, HTWOS B



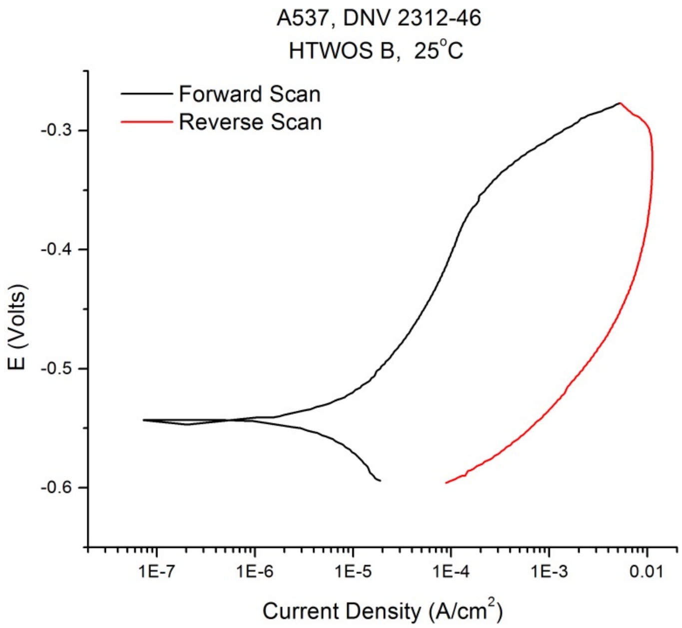


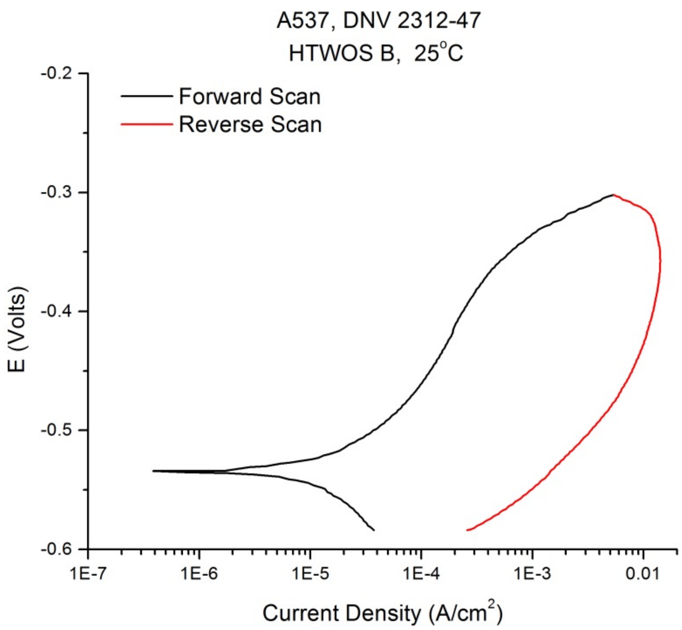
Cyclic Potentiodynamic Polarization Test 2312, HTWOS A



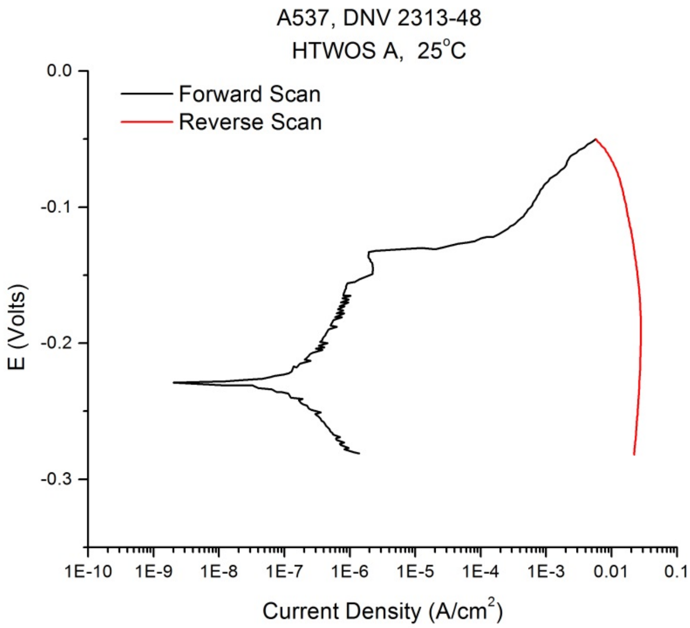


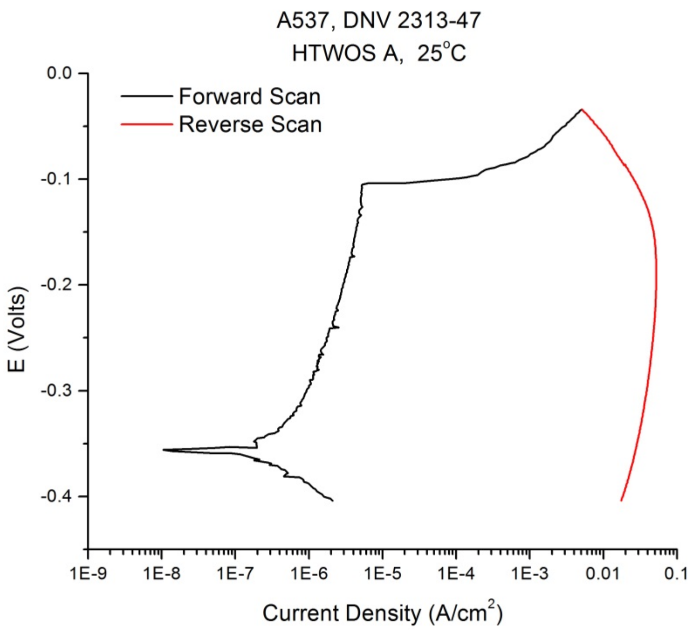
Cyclic Potentiodynamic Polarization Test 2312, HTWOS B



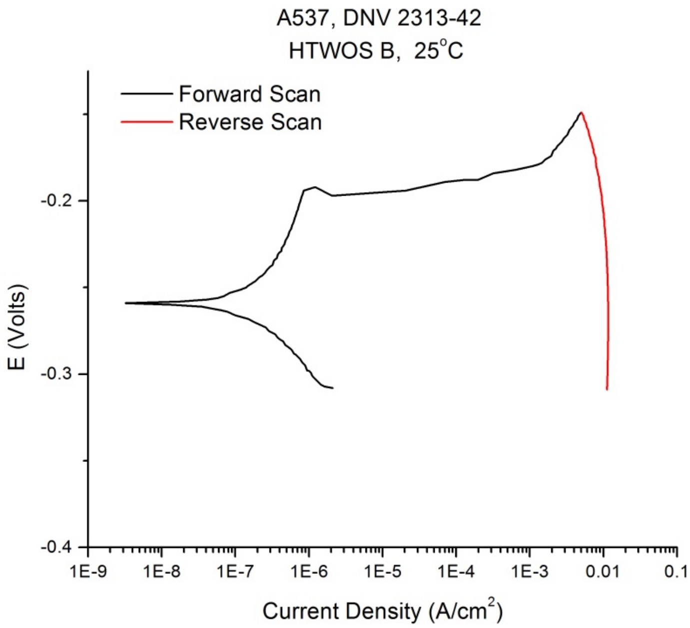


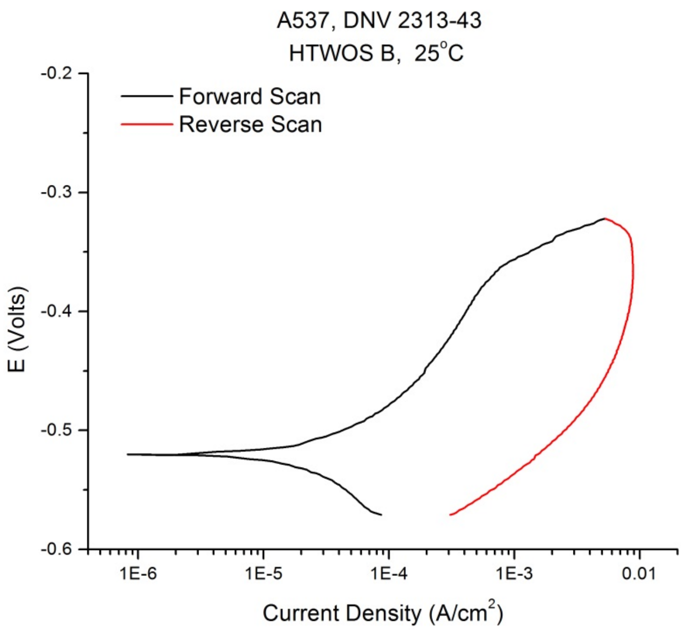
Cyclic Potentiodynamic Polarization Test2313, HTWOS A



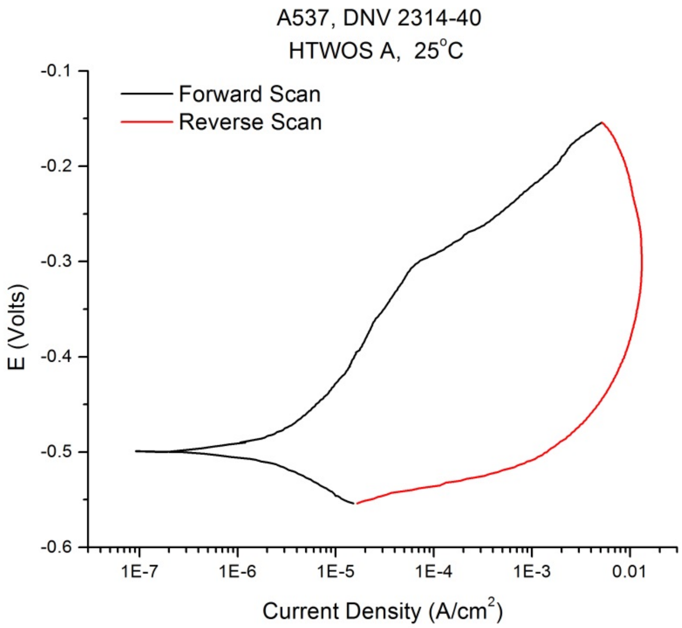


Cyclic Potentiodynamic Polarization Test2313, HTWOS B

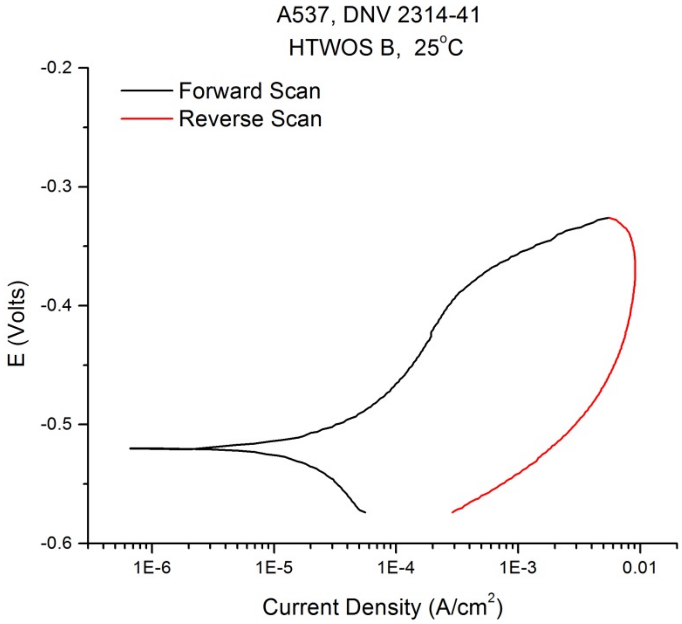


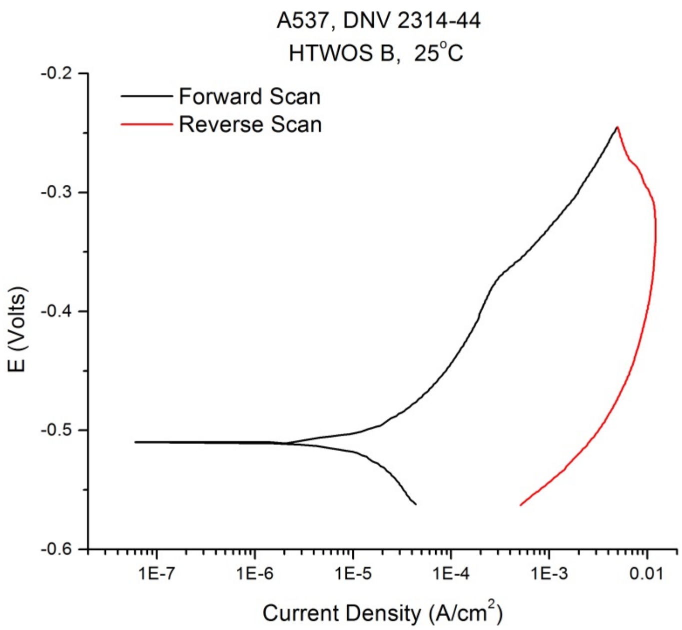


Cyclic Potentiodynamic Polarization Test2314, HTWOS A

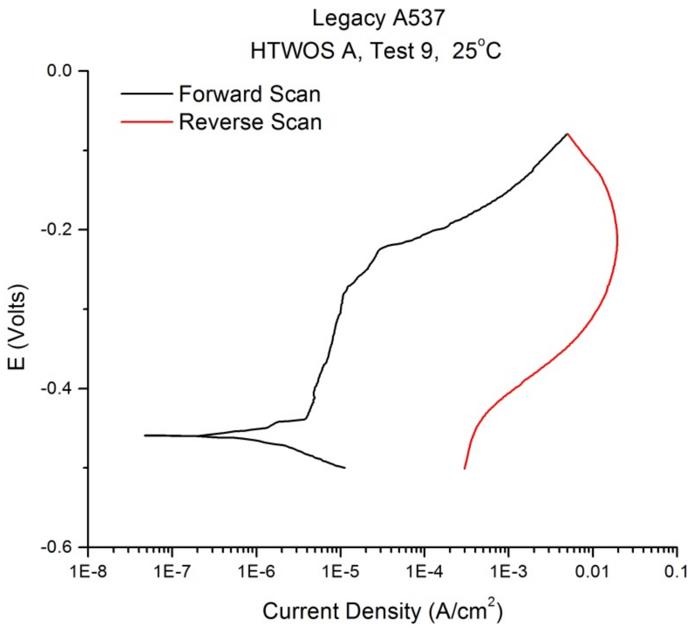


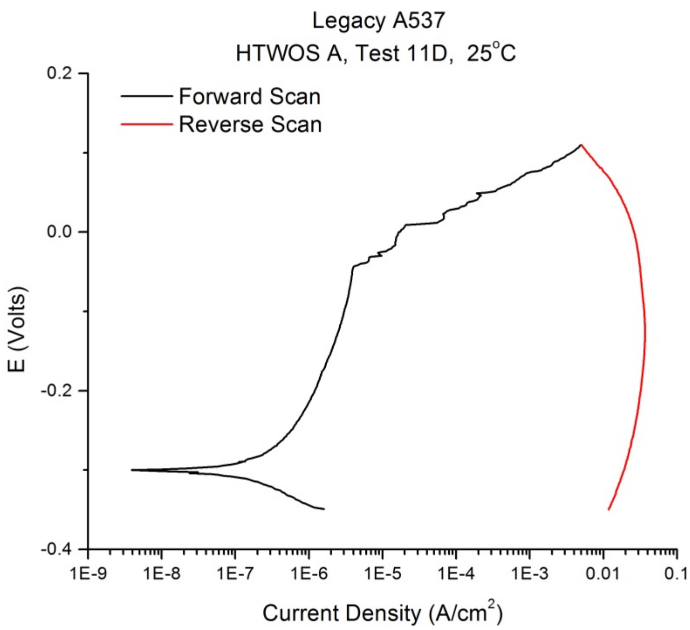
Cyclic Potentiodynamic Polarization Test 2314, HTWOS B





Cyclic Potentiodynamic Polarization Legacy Steel, HTWOS A





Cyclic Potentiodynamic Polarization Legacy Steel, HTWOS B