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Comparison of VCI and CP Performance Using Floor Scan Data from Several 10-Year Old AST Floors

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ABSTRACT

An especially noteworthy and important analysis will be provided on the real-time field performance of stand-alone vapor corrosion inhibitor (VCI) systems in comparison to cathodic protection (CP) systems on aboveground storage tank (AST) floors. API 653 floor inspection data will be presented on a group of (12) AST's that all had completely new steel floors installed, then were inspected (7-10) years later with magnetic flux leakage (MFL) and ultrasonic testing (UT). VCI was used to control soil-side corrosion on approximately 42% of the tanks and CP was used on the other 58%. The tanks resided inside pipeline stations located within 200-miles of each other. Construction materials and practices were very similar for the new tank floors. API 653 floor inspection data produces definitive statistics on the effectiveness of soil-side corrosion control systems for each tank floor. Corrosion control system descriptions and compilations of inspection data for each tank floor are provided and contrasted among the entire sample group.

Key Words: aboveground storage tank, AST, soil-side corrosion, vapor corrosion inhibitors, VCI, cathodic protection, CP, mils per year, MPY

INTRODUCTION

CP has long been an accepted science/technology to utilize for mitigation of AST soil-side corrosion. The use of VCI for the same purpose on ASTs began in the field approximately 20-years ago on a small scale. Since then VCI has been applied under many tanks in the U.S. and throughout the world while also extensively studied in laboratory settings[1]. This has logically resulted in a long-standing question among Industry and Regulatory communities:

How does AST soil-side corrosion mitigation performance compare between VCI systems and CP systems over a long length of time on actual tanks in field applications?

At long-last, a significant volume of tank floor plate soil-side corrosion inspection data has been generated from (7-10 years old) tank floors where only VCI, or only CP were applied for corrosion mitigation. Corrosion anomaly indication data, along with corrosion rate calculations, from floor scan testing performed during initial API Standard 653[2] out-of-service inspections are provided for a group of (12) tanks. All (12) tanks received totally new steel floors, then were inspected (7-10) years later. VCI was solely used to control soil-side corrosion on (5) of the tanks and CP was solely used (7) tanks.

FIELD FORMAT FOR COMPARATIVE EVALUATION

Numerous AST maintenance and upgrade activities were completed within the stations of a pipeline company between the years of 2006-2011. These activities have produced extremely meaningful real-time field data from which to evaluate and compare the performance of VCI and CP corrosion control technologies on multiple tanks.

The key components attributing to the significance of the data include the following:

- Every tank received all new floors. Therefore, floor scan data represents only the soil-side corrosion that occurred during the interval between the new floor construction and the subsequent API 653 inspection.
- Soil-side corrosion control systems utilized were VCI for double bottom tanks and CP for single bottom tanks. The systems were installed during the tank floor construction and active throughout the stated intervals.
- The tanks resided inside (3) pipeline stations located within 200-miles (322 km) of each other. The climate at these stations is semi-arid.
- Construction materials, practices and contractors were very similar for all of the new tank floors.
- The API 653 inspections and floor scans were performed by one of two companies.

The tank upgrades included the following characteristics:

- The tanks utilizing VCI systems originally had single bottoms overlain by a unique concrete pad, then were upgraded with a new second bottom above the original floor. The old floor and new floor were separated by a new sand pad of varying thickness.
- The tanks utilizing CP systems were originally single bottoms. The original bottoms were removed and replaced. The original sand pad was removed and replaced with a new sand pad.
- The diameter of all tanks were either (117 or 120) feet (35.7 or 36.6 meters)
- All of the tanks received totally new floors constructed of A-36 grade steel plates. The annular plates were 0.315 to 0.375-inch (8.0-9.5 mm) thick steel and the width of the internal plates were 0.250 in (6.35 mm) except for one tank that received 0.313 in (7.95 mm) floor plates.
- It is not certain if a specification for the sand properties was utilized during this period. The tank pad sand generally came from the same source for all tanks. Therefore, all electrolyte in contact with the new steel is presumed to have had very similar properties. Sand contamination during tank pad construction may have varied.

SYSTEM DESCRIPTION FOR TANKS WITH VCI ONLY

The time period for most of the new floor/VCI installation was 2007-2008. Station A Tank 1 had the new floor/VCI installed in 2011. All of the tanks utilizing the VCI systems received the same VCI product and the same dosage rate of the chemistry.
NOTE: Since the time of these VCI installations, standard practice has been modified to apply a 60% higher dosage of the same VCI product.

The VCI product for the 2007-2008 tanks was applied in a powder form as follows:

- Drums of VCI powder were shipped to the pipeline stations for application by the tank repair contractor at the site.

- The VCI powder was either raked into the sand pad during its construction or the VCI was mixed into the sand before it was applied onto the pad.
- NOTE: This VCI application process was the only option for these tanks during this time period and was not ideal due to lack of controls. The present recommended practice is aligned with the installation performed on the 2011 tank.

The VCI product for the Station A - Tank 1 was applied in a powder form as follows:

- By this time, the VCI manufacturer had improved the options for application under ASTs.
- The VCI powder was contained and packaged in Tyvek pouches 6 in wide by 10 in long (152.4 mm x 254 mm). Each pouch contained 0.72 pounds (327 grams) of powder.
- The pouches were left connected in 42 feet (12.8 m) long strips and stacked in cartons accordion- style. This made VCI installation much easier and controllable.
- The strips were installed prior to sand pad construction. They were laid out in parallel with the strips separated by approximately (10) feet (3.0 m).

Corrosion rate monitoring of the sand (electrolyte) inside the interstitial space between the floors was installed on all of these tank. Electrical resistance (ER) probes were installed 90-degrees apart by drilled access holes in the dead shell and placing the probes a few inches below the new upper floor.

SYSTEM DESCRIPTION FOR TANKS WITH CP ONLY

The time period for the new floor/CP installation was 2006-2009. The CP systems were installed shortly after the floors were completed and have been in continual operation since that time. CP system information includes the following:

- All CP systems utilized anode groundbeds installed a few feet below the floors with horizontal directional drilling equipment.
- Dedicated rectifiers were connected to each groundbed.
- The output of each tank specific groundbed has consistently equaled approximately (2) milliamps per square foot of floor surface since installation.
- The CP systems for all tanks have operated 90% or more of the time since they were installed.
- Perimeter and undertank potentials were measured to assess CP effectiveness.
- All tanks achieved Regulatory compliance criteria every year since the new floors were installed.

API 653 INSPECTION / FLOOR SCAN INFORMATION

The soil-side floor plate non-destructive testing (NDT) data produced as part of the overall API 653 inspection conducted on each tank are provided in this paper. These data provide the basis upon which the effectiveness of VCI and CP are evaluated and compared.

All of the tanks included in this paper were inspected by one of two prominent providers of API 653 inspection services. The NDT techniques utilized to evaluate soil-side corrosion on all tank floors included:

- MFL scans to identify areas that exceeded or were closely approaching the specified critical floor plate thickness.

- UT technology was then employed to produce quantitative measurements within the areas of corrosion identified from the MFL survey.
- All floor plate surfaces accessible to this equipment were inspected.

A criterion for the remaining floor plate thickness threshold was specified prior to each inspection. Therefore, only corrosion indications that were equal to, or less than, the remaining thickness threshold were recorded in the reports. The thickness thresholds for the inspections performed on the tanks included in this paper ranged from 0.220 in to 0.185 in (5.6 mm to 4.7 mm) on the 0.250 in (6.35 mm) thick floor plates inside the annular ring.

Since the thickness threshold for some tanks was 0.185 in (4.7 mm), this report provides all the comparable corrosion indication thickness data equal to or less than 0.185 in (4.7 mm). Corrosion indication remaining thickness data greater than 0.185 in (4.7 mm) is not provided except for Station A – Tank 6. The internal plates of this tank floor are 0.313 (7.95 mm) thick. Corrosion indication thickness data equal to or less than 0.225 in (5.7 mm) represent a similar percentage of metal loss and are provided for this tank.

INITIAL INSPECTION CONSIDERATIONS

The sand in contact with the bare steel floor plates is a very important corrosion cell component. This sand is the electrolyte of the corrosion cells that form on the soil-side. Corrosion control systems are installed to mitigate the corrosion resulting from the natural reaction of the steel contacting the electrolyte.

A phenomenon commonly observed during the initial AST floor scan inspection conducted a few years after new floor construction is the identification of accelerated corrosion at locations where foreign materials/contaminants in the sand pad (electrolyte) are in contact with the floor plates. This is typically the result of unclean sand; and/or foreign materials/contaminants added to the sand pad during construction as a result of poor sand handling/installation practices. It is commonly understood that some types of foreign materials/contaminants may shield the floor plate steel from VCI molecular distribution and also shield the steel from the protective CP currents. During the first inspection process, steel patches are typically installed over areas of accelerated corrosion that meet or exceed a pre-defined remaining floor plate thickness criterion. Therefore, corrosion control systems then become important for mitigation of the more “general” corrosion on the rest of the floor plates in the years following the initial inspection.

FLOOR INSPECTION DATA AND RESULTS

The tables and graphics in this section provide the remaining floor plate thickness data at each identified corrosion indication; and the average mils per year (MPY) rate of corrosion calculated from the length of time between floor construction and the initial inspection.

- The remaining floor plate thickness is provided in mils or inches.
  (1-mil = 0.001 inches = 25.4 micrometers (µm))
- The average corrosion rate of each indication is calculated by dividing total metal loss with number of years between initial floor construction and the initial API 653 inspection. Example: An indication of 185-mils (4.7 mm) that developed over a 10-year time period on a 250-mil (6.35 mm) thick floor plate = 65-mils/10-years = 6.5 MPY (165.1 µm/yr)

Table 1. Total number of Station A corrosion indications per remaining floor plate thickness segments

	Tanks With VCI Only			Tanks With CP Only				
Tank #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
New Floor/ Yr. Inspected	**2011/ 2018**	**2008/ 2017**	**2007/ 2017**	**2009/ 2019**	**2008/ 2018**	**2008/ 2018**	**2007/ 2017**	**2007/ 2016**
Tank Dia. (feet)	**117**	**117**	**117**	**120**	**120**	**120** *(0.313" floor)*	**120**	**120**
Remaining Thickness (inches)	**Total Corrosion Indications at Specified Remaining Thicknesses**							
0.225-0.197						10		
0.185-0.183	4	4	8	2		1	18	44
0.180-0.178	1	5	3		5		12	40
0.175-0.173			4		3		3	20
0.170-0.168		3		2			1	10
0.165-0.163					2	1	2	11
0.160-0.158	1						2	8
0.155-0.150		7		2				9
0.145-0.140		1				1	1	5
0.135							1	2
0.125								3
0.120							1	
0.100								1
0.090-0.083							2	1
Total Indications	**6**	**20**	**15**	**6**	**10**	**12**	**43**	**154**

Table 2. Total number of Station A corrosion indications per MPY metal loss average segments

	Tanks With VCI Only			Tanks With CP Only				
Tank #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
MPY Avg.	**Total Number of Indications per Specified MPY Range**							
6.0-6.9			8	2			18	
7.0-7.9		9	7		8		15	71
8.0-8.9		3		2	2	1	3	40
9.0-9.9	4					3	2	14
10.0-10.9	1	4		2		2		14
11.0-11.9		3				4	2	8
12.0-12.9	1	1				1		2
13.0-13.9							1	3
14.0-14.9						1		
16.0-16.9						1	2	1
18.0-18.9								1

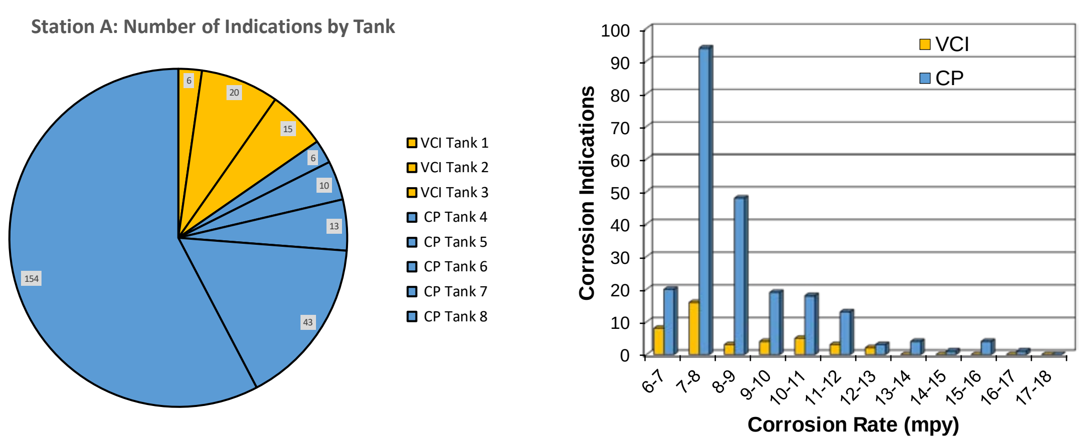

Figure 1. (a) Station A total number of corrosion indications per Tank. (b) Total number of corrosion indications per corrosion rate segments of Station A tank floors.

Table 3. Total number of corrosion indications per remaining floor thickness segments

	Station B		Station C	
	VCI Only	CP Only	VCI Only	CP Only
Tank #	#9	#10	#11	#12
New Floor/ Yr. Inspected	2008/ 2018	2006/ 2016	2008/ 2018	2007/ 2017
Tank Dia. (feet)	117	117	117	120
Remaining Thickness (inches)	Total Corrosion Indications at Specified Remaining Thicknesses			
0.185-0.183		25	7	1
0.180-0.178		20	4	
0.175-0.173	1	14	1	4
0.170-0.168		12		1
0.165-0.163		14		1
0.160-0.158		4		1
0.155-0.150		9		
0.145-0.140		5	1	
0.135		5		
0.125		1		
0.090-0.083		1		
0.053		1		
Total Indications	1	111	13	8

Table 4. Total number of corrosion indications per MPY metal loss average segments

	Station B		Station C	
	VCI Only	CP Only	VCI Only	CP Only
Tank #	#9	#10	#11	#12
MPY Avg.	Total # of Indications per MPY Range			
6.0-6.9		25	7	1
7.0-7.9	1	34	5	4
8.0-8.9		26		2
9.0-9.9		7		1
10.0-10.9		8	1	
11.0-11.9		8		
12.0-12.9		1		
16.0-16.9		1		
19.0-19.9		1		

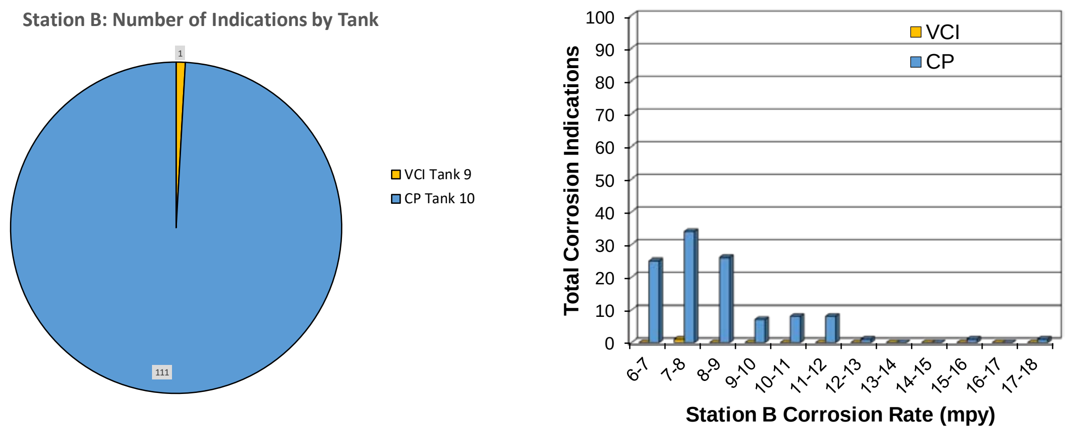

Figure 2. (a) Station B total number of corrosion indications per Tank. (b) Total number of corrosion indications per corrosion rate segments of Station B tank floors.

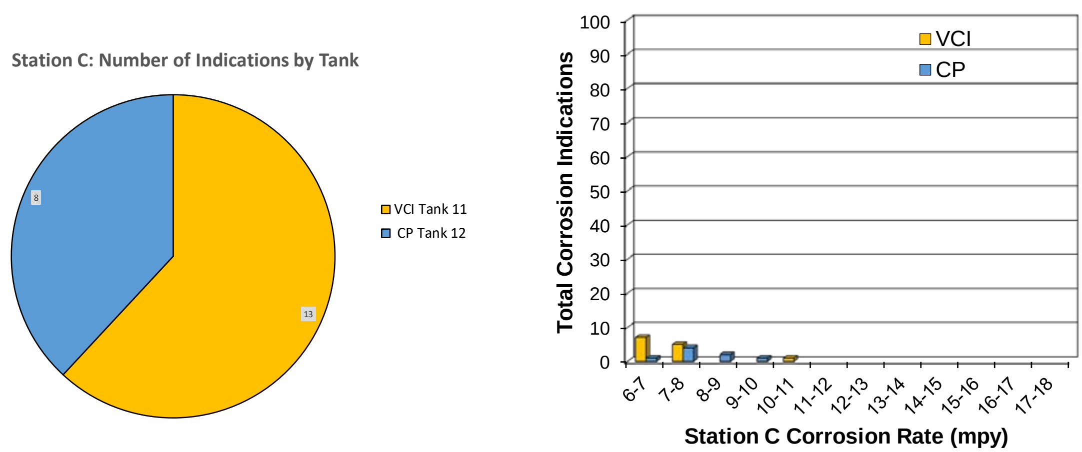

Figure 3. (a) Station C total number of corrosion indications per Tank. (b) Total number of corrosion indications per corrosion rate segments of Station C tank floors.

DATA SUMMARIES

The following Figures provide graphic depictions of the data sets for all (12) tanks located within the (3) Pipeline Stations.

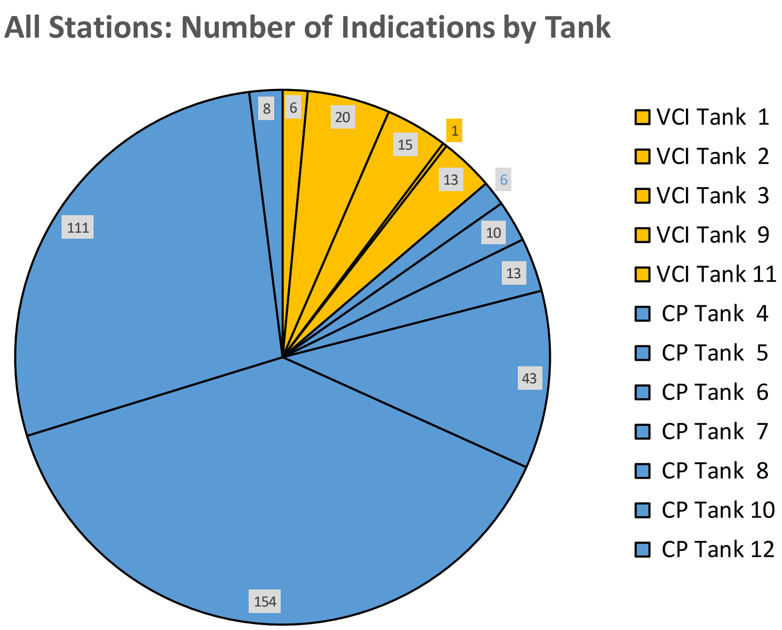

Figure 4. Total number of corrosion indications per all (12) tanks

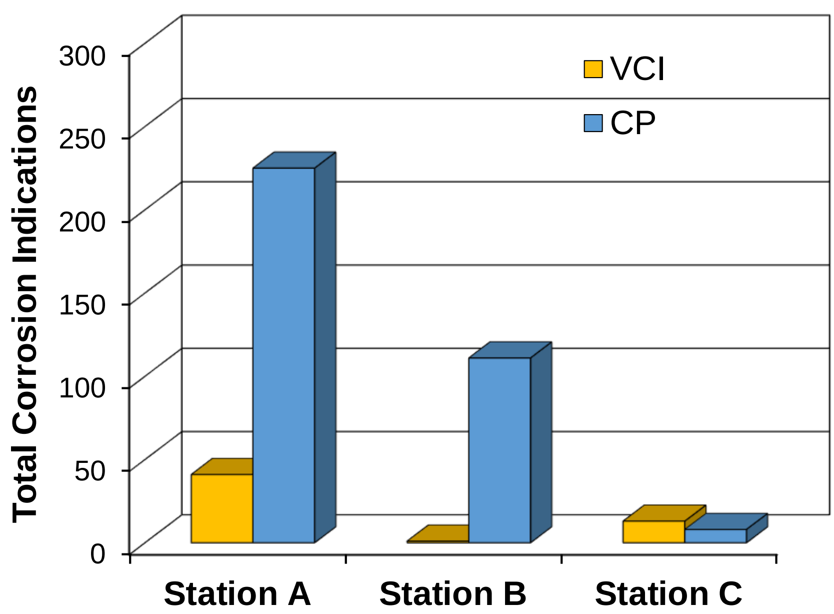

Figure 5. Total number of corrosion indications per each Station

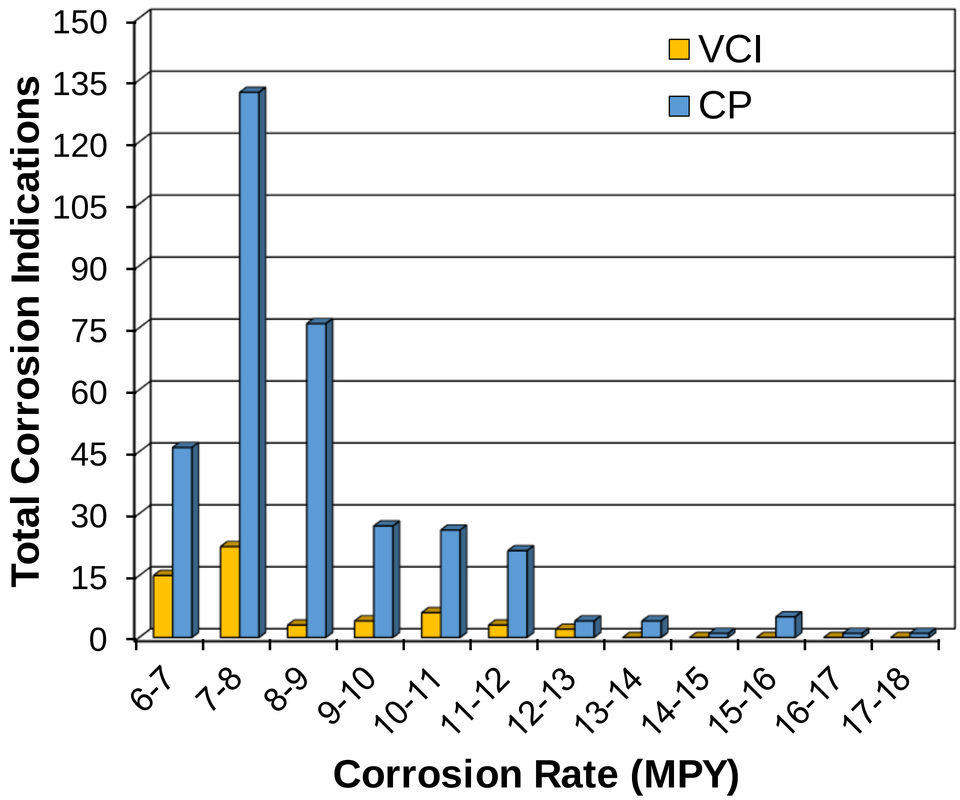

Figure 6. Total number of corrosion indications per corrosion rate segments of all (12) tank floors.

CONCLUSIONS

As explained throughout this paper, the tanks included in this analysis provided an excellent format for side-by-side comparison of VCI and CP where each technology is solely utilized to mitigate soil-side corrosion on new tank floors over a (7-10) year time interval. The utilization of soil-side floor scan data generated during API 653 inspections produced an accurate data set from which to make the comparisons.

The data produced the following interpretations:

1) VCI and CP corrosion indication data were statistically comparable for all (5) VCI tanks with (4) of the CP only tanks (numbers 4,5,6,12).

2) All (5) VCI only tanks performed significantly better when compared to the other (3) CP only tanks (numbers 7,8,10)

3) The reasons for the large disparity in the (3) CP only tanks (numbers 7,8,10) are not understood at this time. There were no operational issues with the CP systems. No information was recorded during the inspection of these (3) tanks to explain the significantly higher number of indications. Speculation on the reasons for these outliers is not included in the scope of this paper.

4) Within this sample group, it is important to note that the differences in the number of corrosion indications for the (5) VCI only tanks were not large.
   a) The total number of indications for the VCI only tanks ranged from 1 to 20; and the average corrosion rates of the indications ranged from 6.5 MPY to 12.9 MPY (165.1 to 327.7 µm/yr).
   b) Whereas the total number of indications for the (7) CP only tanks ranged from 6 to 154; and the corrosion rates of these indications ranged from 6.5 MPY to 19.7 MPY (165.1 to 500.4 µm/yr).

The conclusions derived from the data and subsequent analysis provided in this paper do not necessarily assert one technology superior to the other. However, it is certainly appropriate to conclude that VCI chemistry provides a very viable soil-side corrosion solution for AST floors. The floor inspection data indicates that corrosion mitigation on the VCI only tanks was as effective as the tanks with CP only where the CP was operationally sufficient.

REFERENCES

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