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Comparison of VCI-CP Effectiveness Using Aboveground Storage Tank Inspection Data

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Floor inspection data produces definitive data for determining the effectiveness of aboveground storage tank (AST) soil-side corrosion control systems. Twelve ASTs were inspected seven to 10 years after receiving new floors. The floor inspection data was used to compare soil-side corrosion on five AST floors protected solely by vapor corrosion inhibitor systems and seven AST floors protected solely by cathodic protection systems. The tanks are owned by the same operator and located within a 200-mi (322-km) proximity. Construction materials and practices were very similar for all floors. Corrosion control system descriptions and compilations of inspection data for each tank floor are provided and contrasted.

Cathodic protection (CP) has long been an accepted technology used for mitigation of soil-side corrosion on aboveground storage tank (AST) floors. The use of vapor corrosion inhibitor (VCI) chemistries for the same purpose on ASTs began approximately 20 years ago. During that time, VCIs have been applied under many tanks in the U.S. and throughout the world. It has also been extensively studied in numerous laboratory settings.[1] This has logically resulted in the following long-standing question among industry and regulatory communities: How does AST soil-side corrosion mitigation performance compare between VCI and CP systems over a long length of time in field applications? At long-last excellent data is available to answer this question.

A significant volume of tank floor soil-side corrosion inspection data has been generated from tanks where only VCI, or only CP, were applied for corrosion mitigation.[2] All tanks in this group received totally new steel floors, then were inspected seven to 10 years later. Corrosion anomaly indication data, along with corrosion rate calculations, from floor scan testing performed during initial API Standard 653[3] out-of-service inspections are provided.

Field Format for Comparative Evaluation

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

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

- Every tank received all new floors. Therefore, floor scan data represent 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 three pipeline stations located within 200 mi (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 diameters of all tanks were either 35.7 or 36.6 m (117 or 120 ft).
- All new floors were constructed of A-36 grade steel plates. The widths of the internal plates were 6.35 mm (0.250 in) except for one tank that received 7.95-mm (0.313-in) floor plates.
- 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 to 2008, with one done in 2011. All tanks utilizing the VCI systems received the same VCI product and the same dosage rate of the chemistry.

The VCI product for the 2007 to 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 available option for these tanks during this time period and was not ideal due to lack of controls. The current manufacturer's recommended practice was followed with the installation performed on the 2011 tank.

In the 2011 installation, the VCI product for Station A: Tank 1 was applied in a powder form with improved technology as follows:

- The VCI powder was contained and packaged in Tyvek† pouches 152.4 mm wide by 254 mm long (6 by 10 in). Each pouch contained 327 g (0.72 lb) of powder.
- The pouches were left connected in 12.8-m (42-ft) long strips and stacked in cartons accordion-style. This made VCI installation much easier and controllable.
- The VCI strips were installed prior to sand pad construction. They were laid out in parallel with the strips separated by ~3.0 m (10 ft).

Corrosion rate monitoring of the sand (electrolyte) inside the interstitial space between the floors was installed on all tanks. Electrical resistance probes were installed through drilled access holes in the dead shell 90 degrees apart. They were only a few inches below the new upper floor.

†Trade name.

System Description for Tanks with CP Only

The time period for the new floor CP installation was 2006 to 2009. The CP systems were installed as follows shortly after the floors were completed. They have been in continual operation since that time:

- 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 ~2 mA/ft^2 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 under tank 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 nondestructive testing (NDT) data produced as part of the overall API 653 inspection conducted on each tank provide the basis upon which the effectiveness of VCI and CP are evaluated and compared.

All tanks 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:

- Magnetic flux leakage (MFL) scans to identify areas that exceeded or were closely approaching the specified critical floor plate thickness.
- Ultrasonic testing 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

TABLE 1. TOTAL NUMBER OF STATION A CORROSION INDICATIONS PER REMAINING FLOOR PLATE THICKNESS SEGMENTS

	Tanks with VCI Only			Tanks with CP Only				
Tank No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
New Floor/Year Inspected	**2011/ 2018**	**2008/ 2017**	**2007/ 2017**	**2009/ 2019**	**2008/ 2018**	**2008/ 2018**	**2007/ 2017**	**2007/ 2016**
Tank Dia. (ft)	**117**	**117**	**117**	**120**	**120**	**120 (0.313-in floor)**	**120**	**120**
Remaining Thickness (in)	**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**

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 ranged from 5.6 to 4.7 mm (0.220 to 0.185 in) on the 6.35-mm thick floor plates inside the annular ring.

Since the remaining thickness threshold for some tanks was 4.7 mm, this report provides all the comparable corrosion indication thickness data ≤4.7 mm. Therefore, remaining thickness data >4.7 mm is not provided except for Station A: Tank 6. The internal plates of this tank floor are 7.95 mm thick. Corrosion indication thickness data ≤5.7 mm (0.225 in) 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 the primary electrolyte of the corrosion cells that form on the soil-side. CP systems are installed to mitigate the corrosion resulting from the natural reaction of the steel contacting the electrolyte. VCI systems will mitigate corrosion resulting from the steel contacting the electrolyte, and also will mitigate corrosion on portions of the floor plates that are not in contact with the electrolyte.

An initial AST floor scan inspection is routinely conducted ~10 years after new floor construction. A phenomenon commonly observed during this first inspection is identification of accelerated corrosion at locations where foreign materials/contaminants in the sand pad (electrolyte) are in contact with the floor plates. This is due to unclean sand from the source, and/or on-site sand handling practices adding foreign materials/contaminants into the sand pad during construction. Various 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.

TABLE 2. TOTAL NUMBER OF STATION A CORROSION INDICATIONS PER mpy METAL LOSS AVERAGE SEGMENTS

	Tanks with VCI Only			Tanks with CP Only				
Tank No.	**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

Floor Inspection Data and Results

Tables 1 through 4 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 in = 25.4 µm).
- The average mpy 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 metal loss/10 years = 6.5 mpy (165 µm/y).

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 No.	**9**	**10**	**11**	**12**
New Floor/Year Inspected	**2008/2018**	**2006/2016**	**2008/2018**	**2007/2017**
Tank Dia. (ft)	**117**	**117**	**117**	**120**
Remaining Thickness (in)	**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**

Data Summaries

Figures 1 and 2 provide graphic depictions of the data sets for all 12 tanks located within the three pipeline stations.

Conclusions

As explained throughout this article, 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 seven to 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 evaluations.

The data produced the following interpretations:

1) VCI and CP corrosion indication data were statistically comparable for all five VCI tanks with four of the

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 No.	**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		

CP-only tanks (numbers 4, 5, 6, 12).

2) All five VCI-only tanks performed significantly better when compared to the CP-only tanks numbers 7, 8, 10.
3) The reasons for the large disparity in the three 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 tanks to explain the significantly higher number of indications. Speculation on the reasons for these outliers is not included in the scope of this article.
4) Within this sample group, it is important to note that the differences in the number of corrosion indications for the five VCI-only tanks were not large.
   a) The total number of indications for the five VCI-only tanks ranged from 1 to 20; and the average corrosion rates of the indications ranged from 165.1 to 327.7 µm/y (6.5 to 12.9 mpy).
   b) Whereas, the total number of indications for the seven CP-only tanks ranged from 6 to 154; and the corrosion rates of these indications ranged from 165.1 to 500.4 µm/y (6.5 to 19.7 mpy).

The conclusions derived from the data and subsequent analysis provided in this article 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 mitigation solution for AST floors. The floor inspection data indicate that corrosion mitigation on the VCI-only tanks was as effective as the tanks with CP-only where the CP was operationally sufficient.

References

1 P. Shukla, et al., "Vapor Corrosion Inhibitors Effectiveness for Tank Bottom Plate Corrosion Control," PR-015-153602-R01 (Falls Church, VA: PRCI, Inc., 2018).

2 T. Whited, "Comparison of VCI and CP Performance Using Floor Scan Data from Several 10-Year Old AST Floors," C2020, paper no. 15065 (Houston, TX: NACE International, 2020).

3 API STD 653, "Tank Inspection, Repair, Alteration, and Reconstruction" (Washington, DC: American Petroleum Institute).

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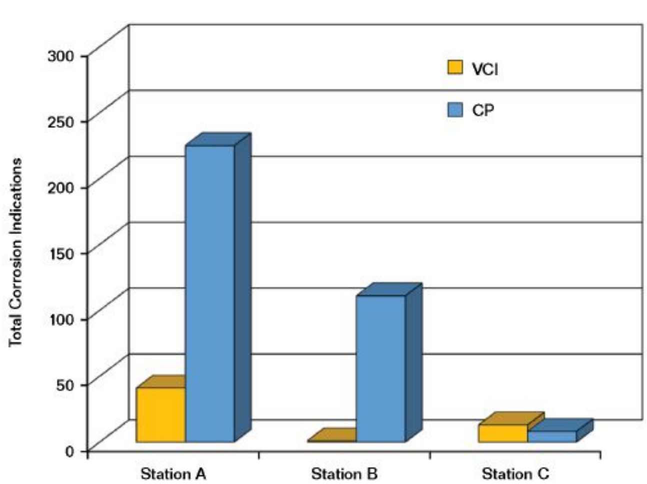

FIGURE 1 Total number of corrosion indications per each station.

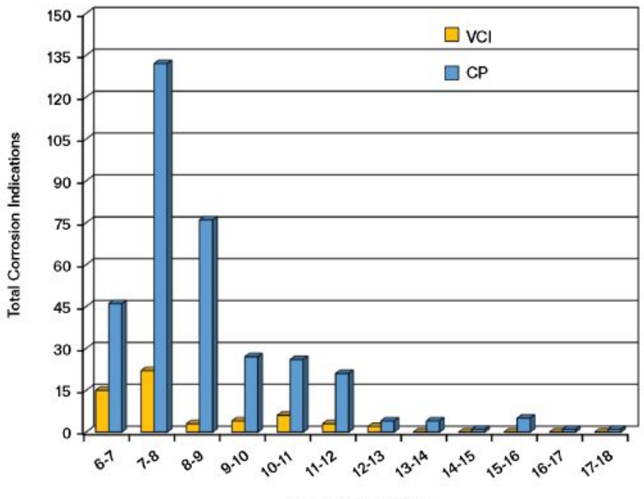

FIGURE 2 Total number of corrosion indications per corrosion rate segments of all 12 tank floors.