

## **Mitigating Soil-Side Corrosion on Crude Oil Tank Bottoms Using Volatile Corrosion Inhibitors**

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### **ABSTRACT**

Soil-side corrosion of the bottom plates of above ground crude oil storage tanks is a major corrosion challenge in the oil and gas industry, especially when these tanks are constructed on oiled-sand pads. Severe corrosion has been identified on tank bottoms at a crude oil tank farm in the Arabian Peninsula. Corrosion led to the costly replacement of bottom plates. The soil-side surfaces of the bottom plates were designed to be protected by a shallow anode impressed current cathodic protection (CP) system. The oily sand layer and air gaps under the bottom plates reduced CP effectiveness and resulted in severe corrosion.

To reduce corrosion damage, volatile corrosion inhibitor (VCI) was injected into the air gap between the sand pad and the underside of the tank bottom during a scheduled maintenance outage. An electrical resistance (ER) probe corrosion monitoring system was also installed underneath the tank. Effectiveness of the VCI treatment was monitored using the ER probe system. Corrosion rate data from ER probes indicated that VCIs were effective in mitigating corrosion on carbon steel bottom plates during the first year after application. Extended monitoring will continue in subsequent years and be the subject of future papers. VCI technology has good potential to reduce crude tank bottom corrosion, reduce maintenance costs, and provide extended service life.

**Key words:** volatile corrosion inhibitors, VCI, oily sand, aboveground storage tank, AST, electrical resistance (ER) probes, tank floor corrosion

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## INTRODUCTION

This paper describes a pilot project that followed the initial investigations described in a previous paper<sup>1</sup>. The pilot project was conducted in 2011 on an aboveground storage tank (AST) at a crude oil tank farm in the Arabian Peninsula. This project was designed to evaluate the procedures for application of volatile corrosion inhibitor (VCI) beneath select areas of the tank floor and then evaluate the effectiveness of the VCI in reducing the corrosiveness of the environment under the tank floor.

For many years throughout the entire Middle Eastern region it has been a common practice for most operators to construct AST floors on tank pads consisting of thick layers of bituminous (oily) sand. The formula for the mixture and the thickness of the oily sand varies throughout the region. Research indicates that the sand contains varying levels of chlorides and moisture. The research also indicates frequent challenges controlling corrosion on the soil side of the tank floors<sup>2 3</sup>. The Yu paper<sup>1</sup> concluded that many corrosion issues are likely related to the inability of cathodic protection (CP) current to flow through the oily sand and effectively distribute throughout the tank floor plate surface. The oily sand presents a high resistance barrier to flow of CP current to the tank floor. Numerous air gaps between the oily sand surface and the tank floor surfaces also negate CP effectiveness, Figure 1. The paper<sup>1</sup> recommended that vapor phase corrosion inhibitors should be injected into the gaps under tank bottoms to mitigate the severe soil-side corrosion as a supplement to the existing CP system.



**Figure 1: Oily sand excavated from below floor plates; air gaps (5-50 mm) under floor plates.**

## PILOT VCI APPLICATION PROJECT

The VCI application pilot project went through a significant design and engineering phase with a specific Saudi Aramco terminal facility targeted for the project. The floor plates of all tanks at the facility are constructed directly on a tank pad that consists of a 0.2 meter thick oily sand layer. Data from past tank floor inspection reports at this facility indicated a predominance of soil-side corrosion was occurring on floor plates within approximately 6 meters of the tank shell. This phenomenon was attributed to a combination of warm moist salt air migration under the floor plates, along with the predominance of significant intermittent air gaps between the floor plates and the oily sand pad. Therefore, this pilot project was developed to evaluate the use of volatile corrosion inhibitors (VCI) as a

means to mitigate soil-side corrosion of AST floor plates. The initial decision was to only apply VCI under the floor plates within a distance of 6 meters from the tank shell. Corrosion rate monitoring was incorporated into the project design, along with a system to seal the gap between the annular plate and the concrete ringwall to prevent migration of fresh air under the floor.

The pilot project was to be performed on an AST that was out of service for Testing & Inspection (T&I). Once the design was completed it was necessary to identify a tank candidate that was scheduled for T&I, then conform the pilot project phases to the T&I project schedule. A very large 107.4 meter (352 feet) diameter crude oil storage AST located at a tank farm in the eastern Arabian Peninsula on the edge of the Arabian Gulf was selected for the pilot project. The field portion of the project was completed in the second half of 2011.

### **Original Pilot Project Scope of Work**

The original design scope of work included the following steps:

1. **Install a real-time corrosion rate monitoring system.**

This included the installation of six electrical resistance (ER) corrosion rate monitoring probes at numerous locations under the tank floor a minimum 2 months prior to the installation of the VCI. A total of four probes were to be located 2 meters from the tank shell; and two probes were to be 4 meters from the tank shell. All probes were to be installed inside of 25 mm schedule 80 PVC pipe so that they could be removed and inspected or replaced in the future if necessary. The pipe was to be located immediately under the tank floor so that the probes would be in the air-gap environment.

2. **Deliver VCI under all floor plates within 6 meters of the tank shell.**

A combination of two methods for delivery of both a liquid and a powder VCI were originally specified.

3. **Install a tape seal to prevent intrusion of outside air between the annular plate and the concrete ringwall.**

A special sealant material was to be applied into the gap between the chime plate and the ringwall, then a tape was applied spanning the chime plate and ringwall surface.

4. **Seal the gaps around the nozzle penetrations.**

The gaps around the two fill, one clean out and three water drain nozzles were sealed in the areas where they penetrated the concrete ringwall.

5. **Obtain ER corrosion rate probe data after VCI Application.**

Data from all corrosion rate probes was then to be obtained after VCI application to monitor effectiveness of VCI.

### **Description of the Selected Corrosion Inhibitor**

Criteria for the VCI necessary to successfully complete this complex project include the following:

- The VCI should control corrosion through the formation of a monomolecular layer throughout the soil-side surface of the tank floor.
- The VCI should have a proven capability of effective molecular migration through the headspace between the floor plates and the tank pad, plus a proven capability of molecular migration through the tank pad soil materials.
- The VCI should be environmentally friendly.
- Molecular adsorption onto the metal surfaces should be accomplished without the need for direct contact of the VCI chemical on the steel floor plates.

- The VCI should have the physical characteristics necessary to emit VCI molecules long-term and be effective during 10-year period between T&I maintenance intervals.

An amine carboxylate based VCI was selected for the project. This product has been in existence for many years and has a long history of successful laboratory evaluations, plus an extensive field application history of effective corrosion mitigation in ASTs and many other complex environments. The formation of a monomolecular layer that is adsorbed onto a metal surface to mitigate corrosion was well understood and documented for this product. The strong propensity of the product to achieve equilibrium when released into an environment and produce molecular distribution through soils and vapor spaces was also well understood and documented. The product was also well researched and tested to verify it as no threat to the environment.

### **Revised Pilot Project Scope of Work**

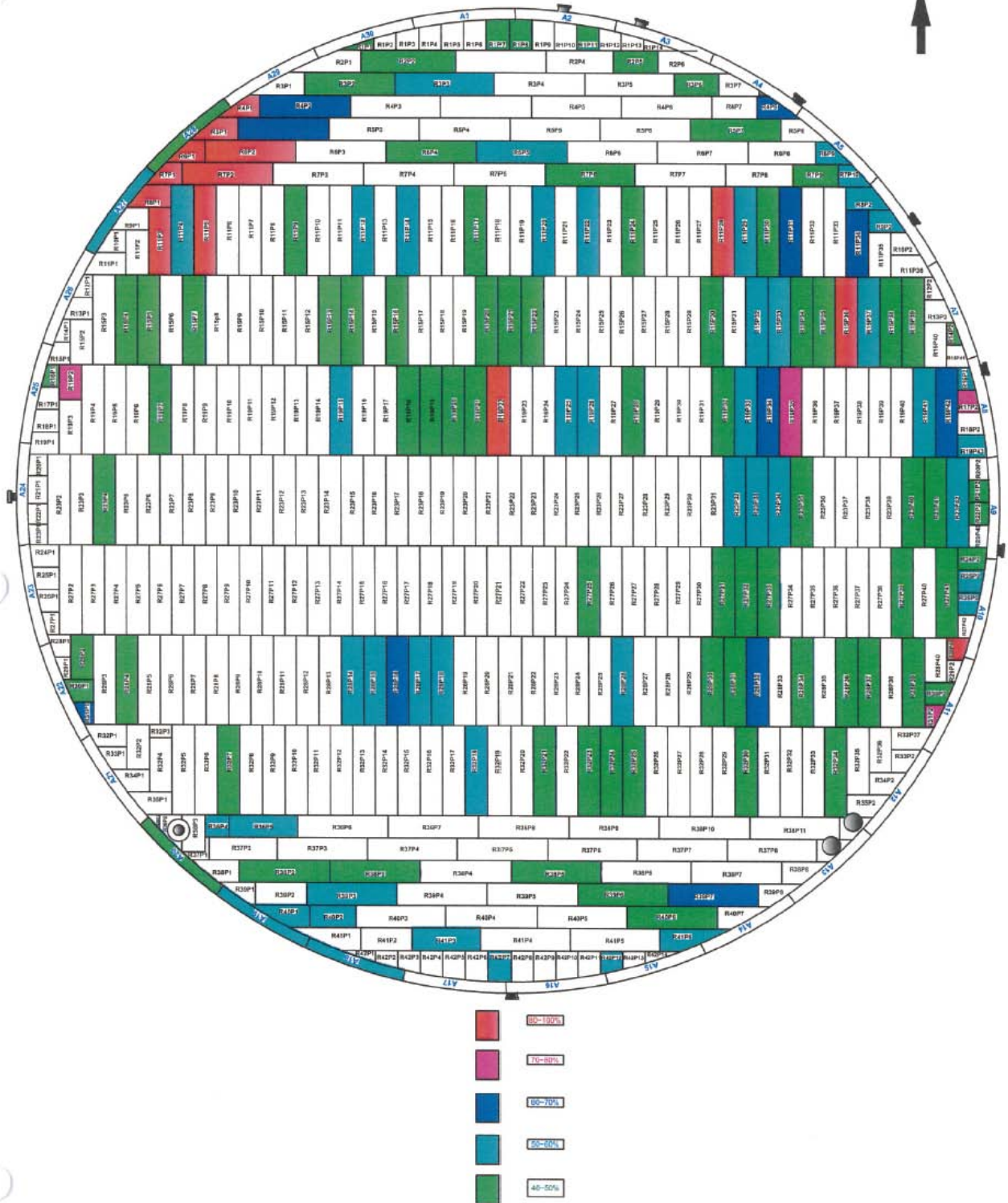
Once the tank to be used for the pilot project had been cleaned and the magnetic flux leakage (MFL)/ultrasonic inspections of the floor were completed, the VCI project team personnel entered the tank to begin the first phase. At that time it was discovered that cement grout had been pumped under the floor plates near the shell during the previous T&I 10 years ago. The grout had been injected through holes in the floor plates and was approximately 10 centimeters thick. The grout layer extended at least 6 meters past the shell around the entire circumference of the tank.

Unlike some of the past floor inspection reports at this facility, the report from the floor inspection identified corrosion in the 6 meter area but also significant random corrosion under many plates throughout the entire floor. Figure 2 provides an example of severe soil-side corrosion on this tank. Figure 3 identifies the different degrees of corrosion from the tank floor inspection report. The inspection results coupled with the existence of the grout under the floor plates caused the project to be revised. The scope of work was modified to include application of VCI chemistry under all plates that had experienced corrosion – not just the plates in the 6 meter perimeter area.



**Figure 2: Soil-side corrosion on pilot project floor plate.**

# Floor Inspection Results Pilot Project Tank



**Figure 3: MFL floor scan results for VCI pilot project tank.**

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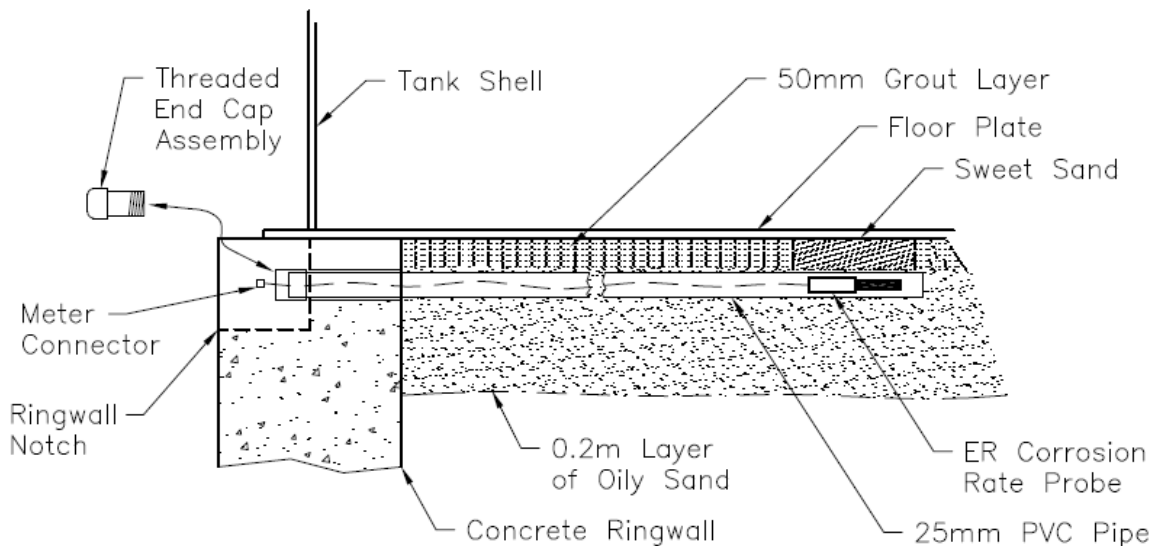
The revised pilot project scope of work included the following steps:

**1. Install a real-time corrosion rate monitoring system.**

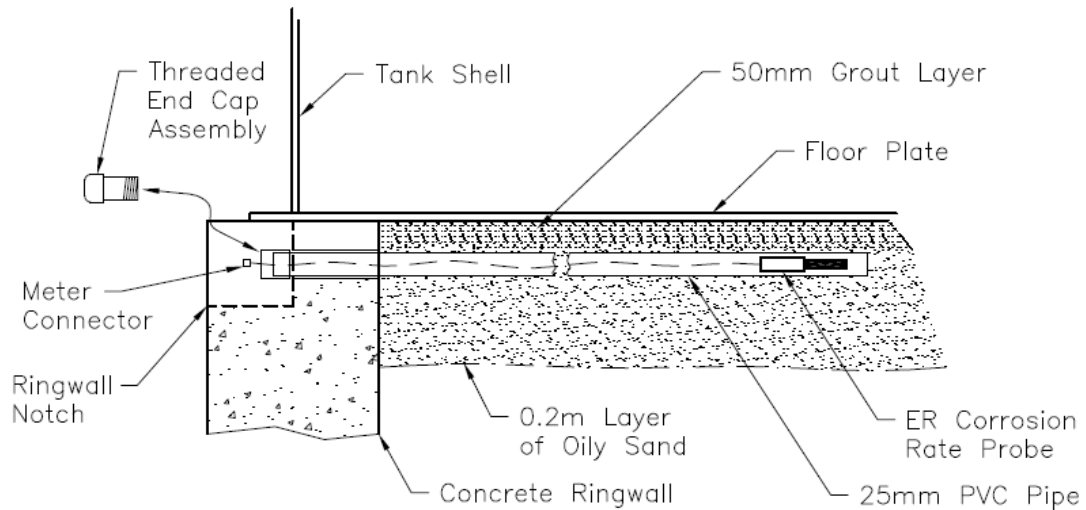
The corrosion rate monitoring system was installed per the original design. The system was installed 2 months prior to the application of the VCI. The locations of the ER probes were chosen by using the MFL scan drawing to identify the area where severe corrosion was noted and the floor plates were not going to be replaced, Figure 7.

The first element of the corrosion rate monitoring system was the installation of the 25 mm PVC piping under the tank floors. A pilot hole was accomplished at the interface of the grout layer and the oily sand. (The pilot hole could not be accomplished above the grout layer.) Then the PVC pipe was pushed into the hole. The leading pipe section was perforated with four rows of 0.5 mm slots and the end was left uncapped. This ensured each ER probe was exposed to the undertank environment.

The floor plate was cut-out above the end of four PVC pipes and the cement grout was removed. Sweet sand was backfilled over the PVC pipe in the ER probe locations, Figure 4. Two of the probes were installed inside slotted PVC pipe located beneath the grout. The floor plate was not removed above these installations, Figure 5.

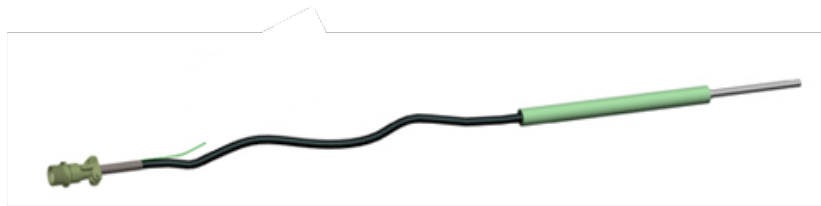


**Figure 4: Typical ER probe installation with grout removed above probe location.**



**Figure 5: Typical ER probe installation without grout removed above probe location.**

The ER probe chosen for the project is depicted in Figure 6. This probe configuration was chosen for compatibility with the PVC access pipes installed immediately under the floor plates. Data from the probes was obtained by connecting to a meter supplied by the probe manufacturer.



**Figure 6: ER corrosion probe used for pilot project.**

**2. Deliver VCI under all floor plates within 6 meters of the tank shell, plus all plates that had experienced severe corrosion.**

A combination of two methods for delivery of both a liquid and a powder VCI were originally specified. The revised plan included injection of VCI powder only through (50) x 20 mm threaded temporary injection ports in the floor plates. The design addressed the 6 meter perimeter floor plate area; and also includes the interior floor plates where corrosion was identified on the MFL Report, Figure 7. Pneumatic equipment was used to effectively distribute 9.5 kilograms of VCI powder through the temporary injection ports under the floor plates a minimum 10 meters in all directions. Steel plate patches were welded over each port after the VCI applications were completed.

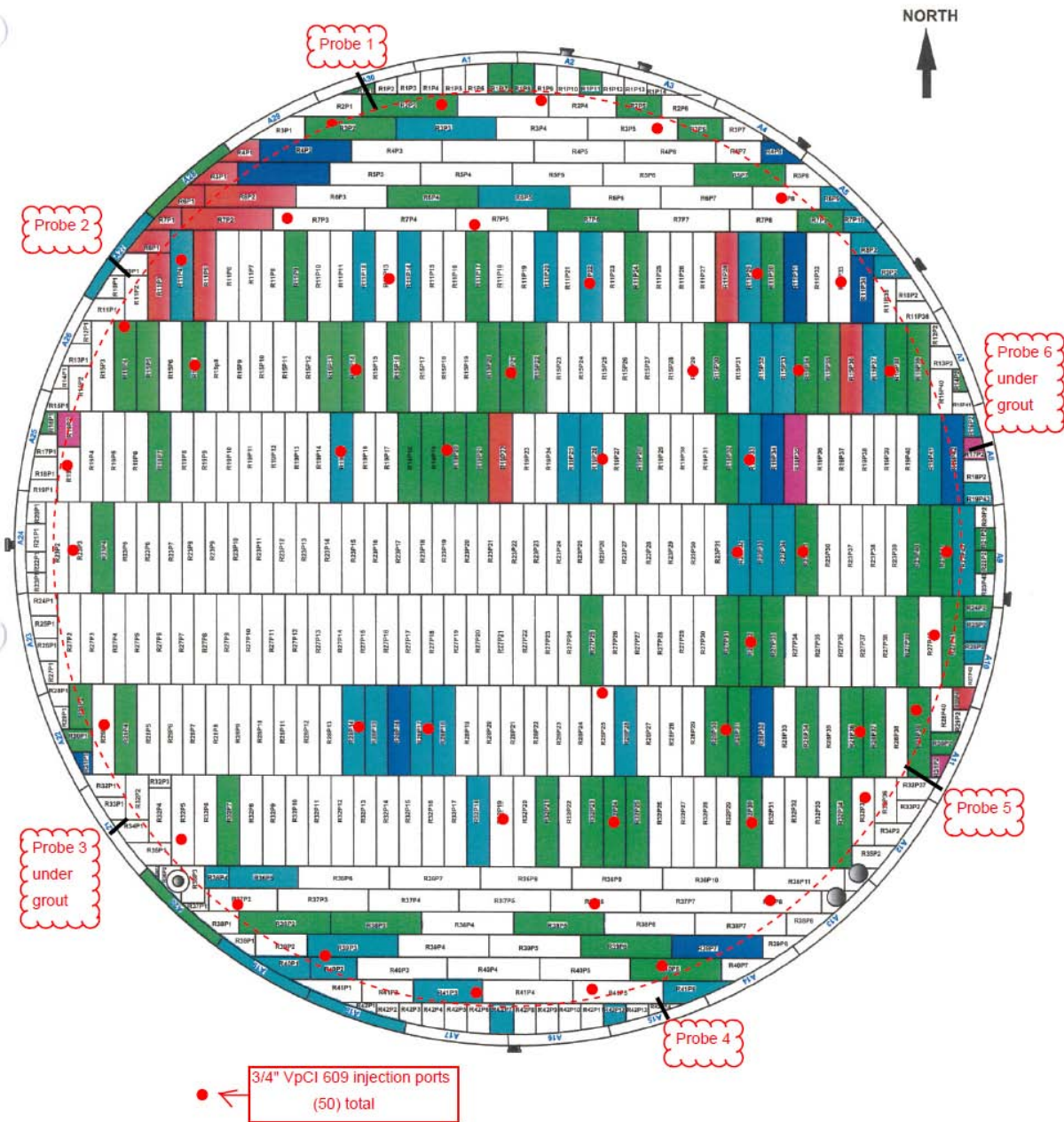
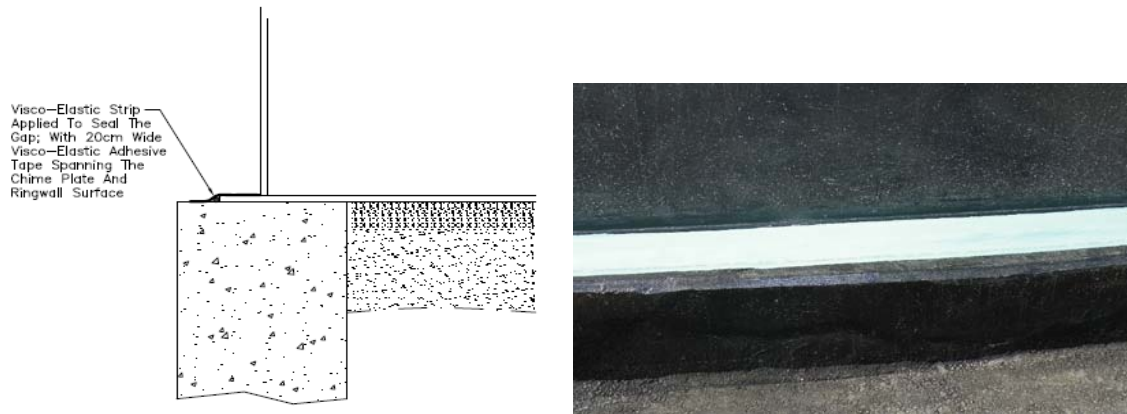


Figure 7: Plan view with ER probe and VCI injection port locations.

**3. Install a tape seal to prevent intrusion of outside air between the annular plate and the concrete ringwall.**

After proper surface preparation, a special visco-elastic sealant paste was to be applied into the gap between the annular plate and the ringwall. Next an adhesive visco-elastic tape was applied spanning the annular plate and ringwall surface, Figure 8.





**Figure 8: Annular plate seal detail and photo.**

**4. Seal the gaps around the nozzle penetrations.**

A total of six large diameter pipes (two fill, one clean out and three water drain) transitioned through into the bottom of the tank floor at various locations. The gaps around the nozzles were sealed in the areas where they penetrated the concrete foundation to prevent intrusion of air and moisture to the tank floor.

**5. Obtain ER corrosion rate probe data after VCI application.**

Data from the ER corrosion rate probes was then to be obtained weekly after application of the VCI to monitor effectiveness of the corrosion inhibitor at each probe location.

**PILOT PROJECT RESULTS**

This pilot project provided excellent information related to the following:

- (1) Procedures for installation of ER probe corrosion rate monitoring systems.
- (2) Procedures for application of volatile corrosion inhibitor chemistry under the floor of an aboveground storage tank.
- (3) Evaluation of VCI physical distribution under the floor plates.
- (4) Evaluation of VCI effectiveness.

**Installation of the Corrosion Rate Monitoring System**

The use of ER probes to evaluate the corrosiveness of the undertank environment is very common in the United States and was effective for this project. There were challenges achieving the undertank installations due to the existence of the cement grout around the tank perimeter. Different processes may be considered for future projects.

**Application of VCI Chemistry under the Floor Plates**

The T&I tank repair contractor was employed to install the temporary injection ports, assist with application of the VCI, then remove the fittings and patch the holes. The process of transferring the port design and configuration from the drawings to the correct locations inside the tank was well planned and executed by the VCI pilot project team. The pneumatic equipment used to inject the VCI powder through the temporary ports and under the floor enabled the specified dosages to be effectively delivered. The entire process resulted in a coordinated effort that was implemented and completed

with a focus on minimal disruption to the overall T&I schedule. The process is now well understood for future projects.

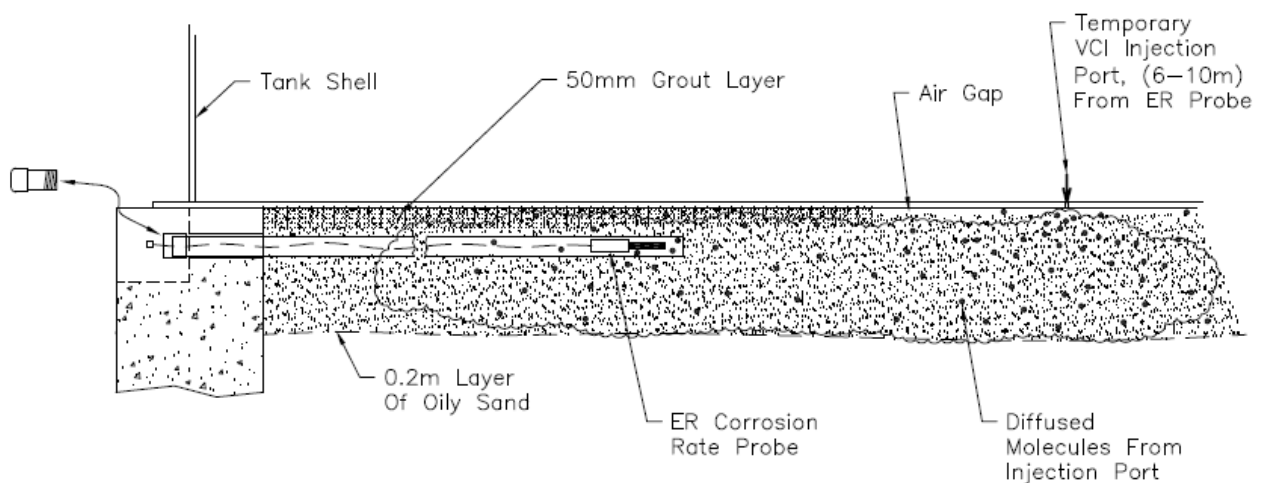
### Evaluation of VCI Physical Distribution

Experience has proven that the floor plates inside an empty tank do not typically lay flat against the tank pad. The floor plates are subjected to significant stresses from the weight of the products when the tank is in service. Therefore the plates beyond the annular plates inside an empty tank normally undulate and are not tight against the tank pad. This provides sufficient air gap for distribution of the VCI powder into a wide radius area beyond the injection ports. The floor in the pilot project tank conformed to this expectation. Monitoring of adjacent injection ports was conducted intermittently during the application of the VCI powder. The VCI was visually observed in the adjacent injection ports to easily migrate distances of 10-meters and greater beyond the injection ports in all directions.

### Evaluation of VCI Effectiveness

The corrosion rate monitoring system was used as the primary tool to evaluate VCI effectiveness in the near-term. It is important to understand that the corrosion rate monitoring system does not measure the rate of floor plate corrosion directly. It measures the corrosiveness of the environment in the vicinity of each ER probe. Since the probes are positioned extremely close (<100 mm) to the tank floor and exposed to the same environmental conditions as the tank floor, there is a direct relationship between the corrosion rate of the ER probe and the tank floor corrosion rate.

The ER probes were located (2 to 4) meters inside the tank perimeter because that was the historical location of the most severe corrosion on ASTs at this facility. Note the proximity of the VCI injection ports to the ER probe locations in Figure 6. The VCI injection ports were not close to the probes. The ports were 6 to 10 meters away from the probes and outside of the concrete grout layer. This design enabled the project team to evaluate the VCI overall effectiveness and molecular distribution through the very dense oily sand and the cement grout applied under the perimeter floor plates, Figure 9.



**Figure 9: Molecular distribution of the VCI through the undertank environment.**

ER probe measurements were obtained weekly over the two months prior to the VCI application, and on a weekly basis for seven months after the VCI was applied. The ER probe data prior to application of the VCI was then compared to the probe data after the VCI was applied.

There are different methods for interpreting ER probe data. For this project linear trend (LT) analysis was applied to the spreadsheet data for each probe to calculate the linear trend “average” rates of corrosion over the 2 month period before and the 7 month period after VCI application. Table 1 provides the results of this analysis.

Probe ID	Distance Inside the Tank Shell (meters)	LT Average Corrosion Rate Before VCI Application (mils per year)	LT Average Corrosion Rate After VCI Application (mils per year)	Percentage of Corrosion Rate Reduction After VCI Application
P1	4	1.26	0.69	45%
P2	2	1.52	0.21	86%
P3	2 <i>See Note 1</i>	0.69	0.0	100%
P4	2	0.49	0.0	100%
P6	2 <i>See Note 1</i>	2.06	0.40	81%

*Note 1: Probe was installed under the 5 centimeter grout layer. VCI molecules had to penetrate the grout and/or oily sand to reach the probe.*

**Table 1: Corrosion rate data results**

This data clearly defines the effectiveness of VCI chemistry in mitigating corrosion within the very difficult environment under aboveground storage tanks. It is significant to observe Figure 9 and note the challenges for effective molecular distribution through the oily sand and cement grout. The project team considers the project a success based upon the initial data.

## CONCLUSIONS

From a corrosion perspective, aboveground storage tanks constructed in the Middle East, and especially tanks constructed in locations near the Arabian Gulf, present corrosion control challenges that are unique in comparison to ASTs constructed in other parts of the world. Given the predominant regional practice of constructing the tanks on oily sand tank pads, typical cathodic protection corrosion control solutions are not always found to be reliably effective.

This pilot project was designed to evaluate the effectiveness of volatile corrosion inhibitors within the undertank environment below a large diameter AST. The tank was constructed on an oily sand pad and the floor plates had experienced severe soil-side corrosion. An amine carboxylate VCI powder product was selected based upon specific criteria. The results of this pilot test indicate that:

- Electrical resistance corrosion rate probes can be used to evaluate the corrosiveness of the environment under ASTs.

- VCI chemistry can be efficiently applied and distributed under AST floors.
- VCI molecules will migrate well beyond the physical product through oily sand and cement grout.
- The amine carboxylate based VCI chemistry produced significant corrosion rate reduction at ER probes located 6-10 meters from the point of VCI powder application.

In summary, amine carboxylate based VCI products effectively applied beneath AST floors, in combination with other practices designed to seal the undertank environment from infiltration of outside air and moisture, were demonstrated to produce an effective corrosion mitigation solution for ASTs.

## **ACKNOWLEDGMENTS**

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